The Met Office Fire Severity Index for England and Wales

Prepared for: Countryside Agency, Countryside Council for Wales and the Forestry Commission

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Contents

ACKNOWLEDGEMENTS 5

ABSTRACT 6

1. INTRODUCTION 7

1.1. Background 7

1.2. Aims and Objectives 7

1.3. Report Structure 8

2. PREVIOUS RESEARCH 9

2.1. Introduction 9

2.2. Background Research 9
2.2.1. Causes and Impact of Fire 9
2.2.2. Fire Risk Management and Indices 10
2.2.3. Defining Exceptional Conditions 11
2.2.4. Guidance and Planning 11

2.3. Additional Analysis 12
2.3.1. Asken Report on Fire Outbreaks during Spring 2003 12
2.3.2. 2003 Trial 12
2.3.3. Statistical properties of the indices 12

2.4. MORECS as a fire severity index 13

2.5. Selection of Indices for Further Analysis 14

3. MODEL SELECTION 15

3.1. Introduction 15
3.1.1. The Canadian Daily Severity Rating 15
3.1.2. The Australian FDI 16
3.1.3. The UK Forestry Commission HRI 16

3.2. Methodology 16

3.3. Analysis of Index Performance 18
3.3.1. Fire severity indices in 1976 and 1995 18
3.3.2. Fire risk in Spring 1980 22
3.3.3. A comparison of indices in 2003 26
3.3.4. Dates of the highest 25 values of the indices at Heathrow 28

3.4. Choice of index 28
3.4.1. Summary of Analysis 28
3.4.2. Assessment of Index Selection 29
3.4.3. Application of the Canadian DSR to different types of vegetation 30
3.4.4. Performance of the DSR against 2003 Trial Data 31
3.4.5. Conclusion 34

4. EXCEPTIONAL CONDITIONS 36

4.1. Introduction 36

4.2. Identifying a Critical Value to Assess Severe Risk 36
4.2.1. Methodology 36
4.2.2. Evidence from 1976 and 1995 36
4.2.3. Evidence from 2003 37
4.2.4. Evidence from Canford Heath fires 38
4.2.5. Summary 39

4.3. Testing the choice of threshold against historical events 40
4.3.1. Methodology 40
4.3.2. Historical monthly maxima of DSR 40
4.3.3. The year 2003 in relation to fixed DSR values 44

4.4. The seasonal change in the critical DSR value 48

5. UNDERSTANDING THE EFFECTS OF USING FORECAST DATA 50

5.1. Introduction 50

5.2. Forecasting the Weather 50

5.3. Verification 51

5.4. Comparing DSR-Obs and DSR-NWP Values 53
5.4.1. 2003 In Context 57
5.4.2. Spring 2003 57
5.4.3. Summer 2003 60
5.4.4. September 2003 61

5.5. Conclusions 62

6. THE MET OFFICE FIRE SEVERITY INDEX 64

6.1. Introduction 64

6.2. FSI Bandings 64

6.3. Factors to consider when defining exceptional conditions 65

7. SUMMARY OF FINDINGS 67

APPENDIX A: LIST OF OBSERVERS FOR 2003 TRIAL 71

APPENDIX B: TABLE OF 25 HIGHEST VALUES AT HEATHROW 72

APPENDIX C: COMPARISON OF CANADIAN DSR TO MORECS 73

APPENDIX D: STATISTICAL ANALYSIS 76

Figures

Figure 1: Canadian Daily Severity Rating 15

Figure 2: Australian Forest Fire Danger Index 16
Figure 3: UK Forestry Commission Fire Hazard Rating Index 16
Figure 4: Comparison between DSR, FDI and HRI: daily values for Heathrow in the summer of 1976 18
Figure 5: Comparison between DSR, FDI and HRI: 5-day running means in 1976 at Heathrow 19
Figure 6: Daily values of DSR, HRI and FDI at Leeming in 1976 19
Figure 7: 5-day running mean values of DSR, FDI and HRI at Leeming in the summer of 1976 20
Figure 8: Comparison between Canadian DSR, Forestry Commission HRI and Australian FDI daily values in the summer of 1995 at Heathrow 20
Figure 9: Comparison between Canadian DSR, Australian FDI and Forestry Commission HRI 5-day running means in 1995 at Heathrow 21
Figure 10: Daily values of DSR, HRI and FDI at Leeming in the summer of 1995 22
Figure 11: 5-day running mean values of DSR, HRI and FDI at Leeming in the summer of 1995 22
Figure 12: Daily values of Canadian DSR, Forestry Commission HRI and Australian FDI at Heathrow in spring 1980 23
Figure 13: Daily values of Canadian DSR, Forestry Commission HRI and Australian FDI at Leeming in spring 1980 24
Figure 14: 5-day running mean values of DSR, HRI and FDI at Heathrow in spring 1980 25
Figure 15: 5-day running mean values of DSR, HRI and FDI at Leeming in spring 1980 25
Figure 16: A comparison of the Australian FDI, the Forestry Commission HRI and the Canadian DSR for April 2003 26
Figure 17: A comparison of the Australian FDI, the Forestry Commission HRI and the Canadian Canadian DSR for summer 2003 27
Figure 18: Mean DSR index corresponding to the observed fire risk in 2003 at sites with grass only, those with grass, heather and bog moss and those with mixed vegetation including trendlines 31
Figure 19: Distribution of Canadian DSR values for all observations 32
Figure 20: Canadian DSR values when Very Low / Low / Moderate / High / Exceptional conditions were observed 34
Figure 21: Monthly Maximum values of DSR for all available years for 8 sites 41
Figure 22: : Daily DSR values for 8 weather stations from January to September 2003 45
Figure 23: Daily DSR values for Heathrow averaged over 1971-2000 for April to June and August to October 48
Figure 24: The monthly mean stress for rough grazing for 1961 – 2004 for MORECS squares 161 and 93 49
Figure 25: Monthly critical DSR values 49
Figure 26: The NWP Process 51
Figure 27: Maximum temperature forecast within 2 °C of observation 52
Figure 28: Verification of the Mesoscale Model (Rain) 53
Figure 29: Comparison of NWP and Observational derived DSR values for Sheffield and Marham 54
Figure 30: Meteorological data -Observations v NWP for Ringway 55
Figure 31: Meteorological data: Observations v NWP for Heathrow 56
Figure 32: 2003 NWP and Observational derived DSR-NWP Mean and Maximum values compared to 30 year trend (January – September 2003) 57
Figure 33: 16th - 23rd April 2003 - % above a range of DSR values and absolute maximum DSR value and daily maps 58
Figure 34: Daily DSR Values for Example Grid Squares in National Park Areas compared to Exceptional thresholds 61
Figure 35: Average, maximum and minimum DSR values across all grid boxes for September 2003 62
Figure 36: Revised monthly critical values 63

Tables

Table 1: Comparative scoring of suitability factors for the DSR, FDI, HRI and MORECS stress indices 29
Table 2 : Class bandings used for comparison of Canadian DSR against observations 32
Table 3: Maximum values of the DSR index calculated at 8 weather stations for 1976 and 1995 36
Table 4: Values of the DSR index above 15 for the high fire risk period in April 2003 for the trial sites 37
Table 5: Maximum values of DSR in April for 8 sites from years between 1971 and 2001 38
Table 6: Values of the DSR index calculated for Hurn on the same days as observed fires on Canford Heath, Dorset 1991-2001. In each month the median and upper quartile values are shown. 38
Table 7: Number of days above thresholds values by site 43
Table 8: Maximum values of the DSR index calculated at 7 weather stations for April 2003 58
Table 9: DSR limits for the Met Office fire risk classes in summer 65
Table 10: DSR limits for the Met Office fire risk classes from October to April 65

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Abstract

The Countryside Agency, Countryside Council for Wales and the Forestry Commission have responsibilities for managing public access introduced under the Countryside and Rights of Way Act 2000 (abbreviated to CROW). Amongst other powers, CROW gives the relevant authorities the right to restrict public access where they are satisfied that, "*by reason of exceptional conditions of weather or any exceptional change in the condition of the land, the exclusion or restriction is necessary for the purposes of fire prevention*".

The Met Office and ADAS Consulting Ltd were asked to develop a fire severity index (FSI) which would give an objective way to show when exceptional conditions occur. Based on research which included literature reviews, statistical analysis and an empirical trial of a range of indices in current use, the Canadian Daily Severity Rating (DSR) is identified as the most appropriate for England and Wales. It is able to effectively distinguish periods of greatest risk in hot, dry summers, wet summers and springtime. It is more sensitive than the other indices tested, with a greater value range, highlighting both specific peaks and gradual increases in risk. It is able to identify fire severity from a range of different weather scenarios and can be used to assess risk for different vegetation types. It also has a strong basis of scientific evidence underpinning its development and is used successfully elsewhere in the world.

The research identifies critical DSR values for defining exceptional conditions, and provides guidance on the start and end of exceptional periods based upon these index values. A banding structure for grouping categories into exceptional, high, moderate, low and very low is included. The index has been implemented operationally to inform decision making and fire management on access land.

1. Introduction

1.1. Background

The Countryside Agency, Countryside Council for Wales and the Forestry Commission have responsibilities for managing public access introduced under the Countryside and Rights of Way Act 2000 (abbreviated to CROW). These bodies along with the National Parks are collectively known as the 'relevant authorities'. While CROW will allow public access on foot to land in England and Wales, it also gives the relevant authorities power to restrict public access where they are satisfied that, by reason of exceptional conditions of weather or any exceptional change in the condition of the land, the exclusion or restriction is necessary for the purposes of fire prevention.

Fire risk is defined as the likelihood of a fire spreading if a source of ignition is present as well as the risk of occurrence of that source. In the UK, fires are most likely to be caused by deliberate action or accidentally (Asken, 2004) rather than natural phenomena such as lightning strikes. The fire risk of an area of land is determined by a combination of the ground and weather conditions. Ground conditions will provide fuel for a fire depending on the volume and dryness of soil and vegetation, and the slope of the land and moisture content in the fuel bed will influence the spread. The weather conditions may influence both the propensity of a fire to ignite through high temperatures, relative humidity and low rainfall, and the likelihood of it spreading due to wind speed and direction. The Met Office and ADAS Consulting Ltd (ADAS) were asked to develop a fire severity index (FSI) which would give an objective way to show when exceptional conditions are present based on analysis of weather conditions. This report gives details of the choice of a fire severity index for England and Wales.

The project to determine the most appropriate fire severity index has involved a number of stages:

- Initially a literature review of the causes of countryside fires in the UK was carried out.
- This was followed by a comprehensive assessment of research into fires and fire severity including interviews with both the relevant authorities and other stakeholders. (Development of a System for the Forecasting of Risk from Fire on Access Land in England and Wales – Stage 1 Project Report, ADAS Consulting Ltd 2002)
- Six existing indices were identified and initially assessed using statistical tests.
- During April to September 2003 a trial took place involving a number of observers around the country taking manual observations of ground state and weather. This allowed the predictions from the indices to be compared to actual impressions of the likelihood of fire occurring on the ground for different vegetation types.
- This led to the short-listing of three indices which were then compared against notable weather events or periods (detailed in this report) to allow the most appropriate index to be identified.
- The selected index was tested against known risk periods to identify a critical value above which conditions were judged to be exceptional.
- The selected index was then built into an operational forecast system. This was run using numerical weather prediction data from 2003 and compared to results gathered from the observational trial for 2003. This provided a final check that the index would capture exceptional risk periods.

1.2. Aims and Objectives

The specific aims of this report are:

- To identify the most appropriate fire severity index for England and Wales based on the following criteria:

- Is the index drawn from a sound scientific base of evidence?
- Does the index emphasise the high risk periods and increase noticeably/dramatically?
- Can the index pick out the increased risk caused by prolonged drought?
- Can the index pick out risk due to combinations of high winds/low humidity/warm temperatures when drought is absent or not severe? (This is particularly important for fire risk in spring.)
- Are all the weather inputs required for the index available from forecast data?
- Is the index based on physical process modelling with a documented scientific backup?
- Does it discriminate well statistically against observations of fire severity?
- Has it been used successfully elsewhere in the world?

- To determine whether a single value of the index can reliably indicate the most severe risk periods throughout England and Wales;
- To determine the most appropriate way of presenting the index in terms of seasonal variations or levels of severity.

1.3. Report Structure

This report begins by summarising previous research undertaken as part of this project by ADAS and the Met Office (Chapter 2). It then outlines the methodology and evaluation of the different indices and identifies the most appropriate (Chapter 3). Chapter 4 describes the analysis to define what constitutes exceptional conditions, and in particular the criteria for the start and end of such periods. Chapter 5 then provides results of the comparison of operational output with observational trial data. Finally Chapter 6 summarises the selected fire severity index.

2. Previous Research

2.1. Introduction

A programme of research was undertaken to identify how fire severity is currently assessed in other countries and which indices may be most appropriate for the UK. From an initial literature review a number of indices were identified and investigated in more depth before being narrowed down to six. These were then tested both statistically and from an empirical trial involving observers in the field whose impressions of fire risk were compared with predictions from the indices. This process resulted in the identification of three indices which are analysed in detail in this report.

This chapter briefly summarises the previous work undertaken as part of the overall project.

2.2. Background Research

This section summarises research conducted in 2002 combining an initial literature review (Gallani, 2002) and the Stage 1 Report for the project by ADAS (ADAS Consulting Ltd, 2002).

It should be noted that the scope of the Stage 1 report was substantially wider than this report in terms of considering the risk of fire ignition and dealing with the suppression of fires as well as severity. Therefore many of the comments from interviews which the report incorporates and subsequent recommendations would provide a framework for a system of fire management. This report, as outlined in Chapter 1, focuses on defining a fire index to indicate exceptional conditions in response to the 2000 CROW Act.

2.2.1. Causes and Impact of Fire

An initial literature review suggested that there are many causes of fires on land which allows public access including:

- deliberate fire setting;
- discarded cigarettes and matches;
- camp fires or barbeques which go out of control or are abandoned;
- discarded glass;
- fallen power lines;
- steam engines;
- weapon fire;
- lightning;
- out-of-control prescribed burning.

In the UK, the majority of countryside fires are caused deliberately or are accidents and the vast majority are associated with the presence of people. Data from Forest Enterprise who recorded the occurrence of fires in their woodlands between 1991 and 1999 showed significant variation year on year from 17 fires in 1998/99 to 883 in 1995/96. In general a correlation is evident between the number of fires and the number of visitors. There was also a noticeable increase in the number of fires during the hot summer of 1995. Five years of records of heath fires in Dorset showed that April and August are the most common months for fires although 24% occurred in the winter (October – March). There was an apparent increase in fires between 4pm and 5pm during school term time.

Fire can cause considerable damage both to the land itself and to the ecological balance in an area. It may impact on the vegetation (for example certain types of heathland may take a long time to grow back), and on birds and other wildlife, either from changes to their habitat or by threatening certain species such as ground nesting birds, for example.

2.2.2. *Fire Risk Management and Indices*

The ADAS report also considered current procedures for fire risk management. Methods for assessing fire risk have been used since the 1940's using combinations of weather variables and land condition to measure fuel moisture content and indicate the ease of ignition. However most of these early methods required some visual estimate of the condition of the fuel and amount of fuel moisture available to be incorporated.
A fire index provides a way to assess the effects of current and previous weather conditions on the risk of fires starting and spreading. Most indices are based on the current day's weather so as to assess the initial risk of ignition and spread, and previous weather to assess the amount of fuel in a suitable state for further burning.

The report identified a number of current indices including:

- the Forestry Commission Fire Danger Rating System;
- the Peak District National Park Fire Risk Assessment Procedure;
- the Dorset Heath Fire Danger Rating System;
- the Canadian Forest Fire Danger Rating System;
- the US National Fire Danger Rating System;
- the Australian Fire Danger Rating Systems.

Forestry Commission Fire Danger Rating System (Peace, 1948)
This is comprised of a fire hazard component and a fire risk component. There are two methods to assess the risk, one appropriate for diverse and scattered blocks of trees where there is little history of fires and the second for large concentrated areas which have a history of fires and above average hazard. A review by the TERRA Environmental Consultancy (Kirby and Tantram, 1999) found that there was a strong tendency for the number of recorded fires to increase with the severity of the danger rating index. Further information about the index is provided in Chapter 3.1.

Peak District National Park Fire Risk Assessment Procedure (Hough, 1997)
This combines input from MORECS (Met Office Rainfall and Evaporation Calculation System) with readings from the field resulting in a Fire Advisory Panel meeting if a high risk is predicted. MORECS is based on a calculated soil moisture state using a model of soil moisture and input weather data from a network of weather stations to give the current state on a particular day. Its main drawbacks are that it has limited rainfall input and results are averaged over quite a large area. Further detail about MORECS is provided in Chapter 2.4.

Dorset Heath Fire Danger Rating System (ENTEC, 2000)
This is based on an assessment of the combined impact of weather and vegetation conditions, with predefined weightings to allow a risk of fire and risk of escalation index to be established.

Canadian Forest Fire Danger Rating System (Van Wagner, 1987)
This has three components: a Fire Weather Index incorporating a daily severity rating; a Fire Occurrence Prediction System and a Fire Behaviour Prediction System covering the full scope of fire management. For the needs of the relevant authorities in response to the 2003 CROW Act, the weather index and severity rating are the key components. The index is calculated from a combination of more specific indices deriving assessments of fuel moisture and drought from weather information. Further details of the daily severity rating are provided in Chapter 3.1.

US National Fire Danger Rating System (Roads et al, 1991)
This system combines predictors of ignition, the rate of spread of fire, and the available energy per unit area of fire with other information to produce four fire danger indices:

1. the lightning caused fire occurrence index;
2. the human-caused fire occurrence index;

3. the burning index;
4. the fire load index which assesses the effort required to contain all probable fires with a specified period of time.

There is also a more simplified version which assumes uniform fuel characteristics. To use this index in England and Wales would require a separate analysis of the state of fuel across the countryside.

Australian Fire Danger Rating Systems (Cheney, 1992)
The most widely used Fire Danger Rating Systems in Australia are the McArthur Forest and Grassland Fire Danger Rating Systems. These give an indication of the difficulties of suppressing fire in either forests or grassland areas and include a drought factor as a key element. Models of predicted rate of spread and fire behaviour are derived separately because of local variability (see Chapter 3.1 for further information).

2.2.3. *Defining Exceptional Conditions*

The Stage One report envisaged that the definition of exceptional could be based upon return periods. For example, 'exceptional' could be set to some index value which occurs once every ten years. This is a method commonly used within meteorology for defining the exceptionality of a meteorological event.

This approach was, however, not taken forward for two reasons. Firstly, using a return period of ten years, for example, would give a different threshold value for different parts of the country. Typically, more northern latitudes may be expected to have a lower index value for the one in ten year event when compared against a more southerly location. To use different threshold values across the country would simply imply that different parts of the population would have different levels of fire risk associated with 'exceptional'. This approach would not then be equitable.

Secondly, simply because an event occurs once every ten years, that alone does not imply that such an event should in any way cause concern. If the one in ten year event is a very low index value, then it illustrates that the area is a low fire risk area generally and the one in ten year event should not necessarily be used as a threshold. Conversely, conditions which may give rise to concern could occur more frequently than once in ten years in some parts of the country. It would not be credible to ignore these occasions simply because they occur more frequently than once in ten years.

The Stage 1 report also references a separate condition of land index. However the three indices which are analysed as part of this report incorporate the effects of different land types. For example, the variation in fuel moisture content at different layers is captured by the fuel moisture code, duff moisture code and drought code in the Canadian daily severity rating. Further work is needed to ensure any index accurately captures different vegetation types.

2.2.4. *Guidance and Planning*

The report identified that there was little good practice guidance issued by organisations not directly responsible for the management of land, apart from in the area of prescribed burning. Some Fire Advisory Panels have been established and part of their remit is to produce fire plans. These contain contact details for all relevant organisations, lists of access and rendezvous points, water resources and roads, fire breaks and areas of important ecological significance. The limited guidance that is available suggests that fire risk assessments should be carried out between March and October as this period includes the higher risk periods for all vegetation types.

2.3. Additional Analysis

2.3.1. Asken Report on Fire Outbreaks during Spring 2003

One of the recommendations from the Stage 1 report was to set up a data collection exercise to build up a database of fire history. The Countryside Agency commissioned a report by Asken Ltd to look into the occurrence and management of fire outbreaks during Spring 2003. This sought data from fire authorities and other organisations involved in countryside management. The report concludes that:

- data recording practices were not well developed and some fire authorities were unable to respond to a request for information;
- fire authority data was unsuited to the monitoring of access land fires;
- there is a clear link between the presence of people and occurrence of fires;
- fire risk management is more effective when there is an official presence on the ground;
- local input on decision making is crucial to effective fire risk management and control.

2.3.2. 2003 Trial

In order to test the indices against actual data, a trial was run in 2003 involving observers at various sites around the country. The aim of the trial was to test the predictions of the indices against a manual assessment of the fire risk on a given day. Data was collected by volunteers at a number of partner organisations (a list of participants is provided in Appendix A) from 32 sites ranging from Devon in the south to Northumberland in the north, and from the Pembrokeshire coast in the west to Bourne, Lincolnshire in the east. The trial ran from 1st April 2003 to 6th October 2003 and observers were asked to comment on:

- their impression of the level of fire risk;
- the general condition of vegetation;
- surface soil conditions (dry, damp or wet);
- wind speed (light, moderate or strong);
- humidity (dry or moist);
- whether it was raining or not.

They were tasked with subjectively assessing the fire danger rating based on personal experience and opinion. Data coverage is not complete either geographically (which would have involved too many observers), or temporally, as some observers were unable to complete an assessment for every day or every element. However it does provide a useful source of actual observations from people with local skill and knowledge of their area.

The information was used in a number of ways including:

- the statistical analysis described below;
- the analysis presented in Chapter 5 comparing the operational output based on the current day's weather prediction and the trial results;
- the assessment of the performance of the final choice of index based on Met Office observational data compared to trial data.

2.3.3. Statistical properties of the indices

An investigation was conducted by ADAS to compare all of the fire severity indices which were identified in the original ADAS report and to test their ability to represent the observations of fire risk which were collected in the 2003 trial. The fire risk assessments were made on a 5 point scale from 1 representing nil risk to 5 representing exceptional risk. The calculated index values for each of these classes were then assessed

statistically in an attempt to see which index gave the best description of the observations. The report is provided in Appendix D and summarises the results from the best performing indices (Canadian, Peak District and Dorset Heath). It concludes that the Canadian DSR gives the most sensitive prediction out of all the indices and is good at discriminating between fire risk classes, especially for exceptional cases.

2.4. MORECS as a fire severity index

Data from MORECS have previously been considered alongside other factors when assessing fire risk in the UK (the Peak District index, for example). MORECS is an acronym for **M**et **O**ffice **R**ainfall and **E**vaporation **C**alculation **S**ystem. It is an operational system for providing routine information on evaporation and soil moisture, not fire risk which would necessitate additional information on ground and weather conditions. For further information on MORECS and its outputs see Hough and Jones (1997).

The output from MORECS, used by some organisations to assess fire risk, is the actual evaporation divided by the potential evaporation, more commonly called stress. Potential rate of evaporation is defined as the atmospheric demand for water unrestricted by soil dryness. The actual rate of evaporation is defined as being equal to the potential rate when the soil is moist, but increasing soil dryness reduces it to below the potential rate. In general:

- When the soil is completely depleted of water which plants can access then MORECS gives an actual evaporation equal to zero.
- The stress is equal to 1.0 when the actual evaporation rate is equal to the potential rate. It decreases to zero when no water is available.

The stress is a measure of soil dryness and therefore can be indicative of vegetation dryness. When the stress has been near zero for some weeks it is likely that the vegetation is largely dead and the soil very dry. The fire risk is then usually considered to be high.

The MORECS stress values are produced weekly (daily values are also available though not in real time) across the UK for 40 km x 40 km square areas. They are available for a range of vegetation and soil types, but most fire risk users take values of stress for the "rough grazing" vegetation option on an average (known as "median") soil.

Prior to the current research, MORECS was the best information available for assessing fire risk in the UK. However there are constraints when using it as a sole measure to assess fire risk:

- MORECS is valid only on the day of issue and there is no forecast element.
- MORECS is not specifically focused on calculating fire risk and was not developed with this in mind.
- Results are averaged over a 40km square, so spatial resolution is less than under the new fire severity index.
- MORECS does not take into account high winds, warm temperatures and air humidity which can increase risk even though the soil may be wet. It would over-emphasize ground conditions, which may disguise the fact that dead vegetation cannot absorb moisture from the ground easily and therefore can still dry out and pose a danger to the spread of fire.

MORECS is due to be replaced by MOSES (Met Office Surface Exchange Scheme) over the next two years. MOSES provides soil moisture data rather than the soil moisture deficit like MORECS and is also produced over a finer resolution (5 km) and at a smaller temporal resolution (hourly). However whilst this has some benefits over MORECS, its primary purpose is still not as a measure of fire risk and therefore would still not provide

as comprehensive an assessment of fire severity as some of the indices described which have been specifically developed for this purpose.

Some of the benefits of MOSES are already captured however within the Met Office's forecast model. Data from MOSES are included in the model during its initialisation step (see Chapter 5 for more details on how the Met Office predict the weather) to capture the different types of land surface.

2.5. Selection of Indices for Further Analysis

The US index, Peak District and the Dorset Heath Index were not carried forward to the final stage of the project. As well as performing less well in the analysis, there were concerns over the robustness of the replication of the US model as the full algorithms were not publicly available. For the comparison analysis in Stage 2, third party software was needed so the detailed workings of the index for operational implementation could not be assessed.

The Dorset Heath model is similar to the Forestry Commission one but depends upon referencing a table of values rather than an algorithm and so is less sensitive. It also requires a measure of soil dryness which cannot be forecast.

The Peak District index uses MORECS and in statistical tests underperformed in distinguishing between exceptional and high values, showing less sensitivity than the Canadian and other models. Hence the final three indices considered were:

- the Canadian index;
- the Australian index;
- the UK Forestry Commission Index.

3. Model Selection

3.1. Introduction

A variety of indices have been developed to assess fire severity in this country and elsewhere, and as outlined in Chapter 2, six were analysed and the following three selected as most appropriate:

- the Canadian Daily Severity Rating (DSR);
- the Australian Fire Danger Index (FDI);
- the UK Forestry Commission Hazard Rating Index (HRI).

This chapter provides a more thorough analysis of the three selected. It begins with a short description of each index followed by an assessment of their relative performance and finally the most appropriate index is selected.

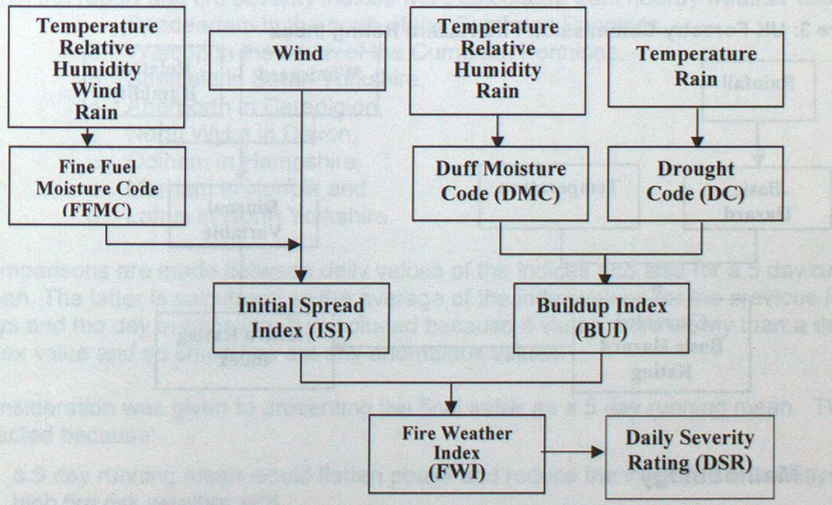
3.1.1. The Canadian Daily Severity Rating

This uses a combination of moisture content of the soil at different levels to produce an index (Van Wagner, 1987). The fine fuel moisture code (FFMC) gives a rating for top level small fuel elements. The duff moisture code (DMC) provides a rating for loosely compacted organic layers of moderate depth and the drought code (DC) indicates moisture levels of deep compact layers in larger fuel elements. The following daily weather data is used:

- 24 hour total rainfall (mm) at noon;
- temperature (°C) at noon;
- Windspeed (km hr^{-1}) at noon;
- Relative humidity (%) at noon.

The three moisture content ratings are combined as shown Figure 1 to produce the Daily Severity Rating. As stated in Chapter 2.2, the Canadian Danger Rating System includes both the production of a Fire Weather Index and a Daily Severity Rating as well as Fire Behaviour and Occurrence Prediction Systems which are beyond the scope of this work. The index for England and Wales would use the Daily Severity Rating and therefore this index will be referred to as the Canadian DSR.

Figure 1: Canadian Daily Severity Rating

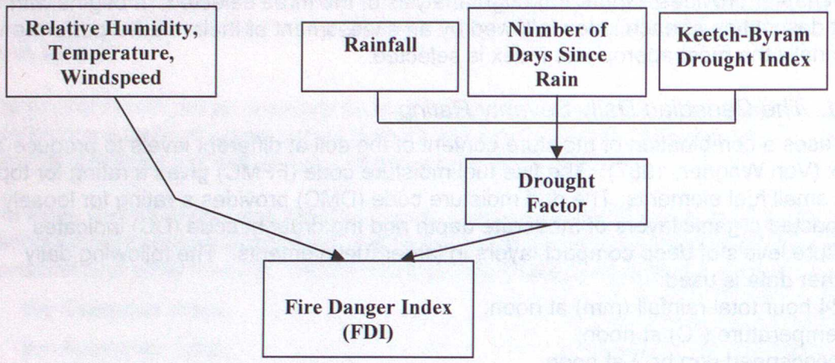


3.1.2. *The Australian FDI*

This differs from the Canadian index in that it incorporates the annual average rainfall as well as the 24 hour total to calculate a drought factor using accumulations of temperature and rain and also the number of days since the last rainfall. (Cheney, 1992) It incorporates:

- 24 hour total rainfall (mm) at 9am;
- mean temperature (°C);
- 10m average windspeed (km hr^{-1});
- relative humidity (%);
- annual average rainfall (mm).

Figure 2: Australian Forest Fire Danger Index

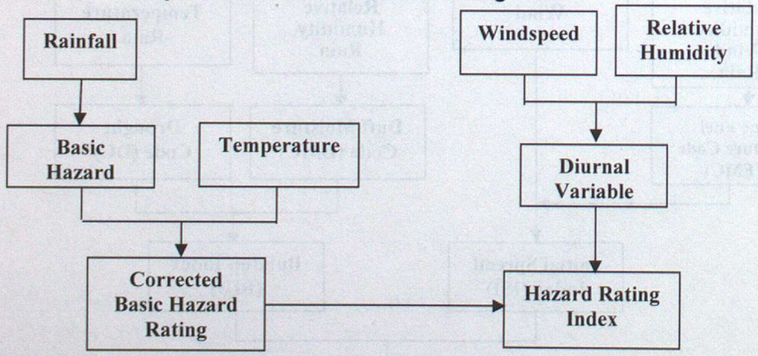


3.1.3. *The UK Forestry Commission HRI*

In this method, rainfall and temperature are considered to determine the basic hazard. (Appendix J in (ADAS 2002)). This is modified by a diurnal risk to produce the HRI incorporating:

- 24 hour total rainfall (mm) at 9am;
- maximum temperature (°C);
- 10m average windspeed (km hr^{-1}) at 9am;
- minimum relative humidity (%).

Figure 3: UK Forestry Commission Fire Hazard Rating Index



3.2. Methodology

The key criteria used to select the most appropriate index included assessments of:

- whether the index can emphasise high risk periods and increase noticeably / dramatically;
- whether the index can show heightened risk during periods of prolonged drought;
- whether the index can pick out risk due to combinations of high winds/low humidity/warm temperatures when drought is absent or not severe.

The behaviour of the indices was compared for the following properties:

- a suitable range of values which emphasise an exceptional fire severity period;
- guidance on variations of risk at all times of the year;
- good discrimination between high and low risk periods.

These criteria were measured by comparing how the indices perform for conditions which are particularly vulnerable to increased fire severity as exemplified by:

- the hot and dry summers of 1976 and 1995;
- the warm, dry spells in the springs of 1980 and 2003.

Two data sets were used to analyse the performance of the different indices. Firstly, a set of daily index values were calculated using daily weather data from 8 weather stations in England and Wales. The period from 1971 to 2001 was used for a set of stations with robust observing records and a good geographical spread. The sites were:

- Heathrow, London
- Hurn, nr Bournemouth
- Marham, Norfolk
- Leeming, North Yorkshire,
- St. Mawgan, Cornwall,
- Aberporth, Ceredigion,
- Ringway, Lancashire and
- Eskdalemuir, Dumfries and Galloway.

Secondly, there was also a set of daily indices calculated for the fire risk trial in 2003. A total of 31 sites were monitored for the likelihood of fire. Eight are used as representative within the report and fire severity indices were calculated from nearby weather stations:

- Spadeadam in the north of the Cumbrian Pennines,
- Warcop in the south of the Cumbrian Pennines,
- Sheffield in South Yorkshire,
- Aberporth in Ceredigion,
- North Wyke in Devon,
- Odiham in Hampshire,
- Marham in Norfolk and
- Loftus in North Yorkshire.

Comparisons are made between daily values of the indices and also for a 5 day running mean. The latter is calculated as the average of the index values for the previous four days and the day in question. It is included because it varies more slowly than a daily index value and so smoothes out any anomalous values.

Consideration was given to presenting the final index as a 5 day running mean. This was rejected because:

- a 5 day running mean would flatten peaks and reduce the impact of a few days of high fire risk weather and
- it would give inadequate warning of fire risk periods as the daily distribution of isolated extreme values which are forecast at any point up to 5 days ahead may be disguised.

Also, for each index, the dates of the highest 25 values were identified within the 30 year simulation. These dates were assessed to check whether they corresponded to known high risk periods.

3.3. Analysis of Index Performance

3.3.1. Fire severity indices in 1976 and 1995

The summers of 1976 and 1995 are widely recognised as having had severe fire risk in England and Wales (Entec, 2000). The index will need to perform well in these years to be selected as suitable. The three fire severity indices are compared for these years. Data from Heathrow near London and Leeming in North Yorkshire are discussed by way of example as both these stations have excellent observing records and are geographically dispersed. Both daily values of the index and a 5 day running mean are analysed. Figures 4 to 8 refer to summer 1976 and Figures 9 to 12 refer to summer 1995. The Australian FDI is shown on the right hand axis whilst the Canadian DSR and Forestry Comission HRI are shown on the left hand axis on all graphs.

Figure 4: Comparison between DSR, FDI and HRI: daily values for Heathrow in the summer of 1976

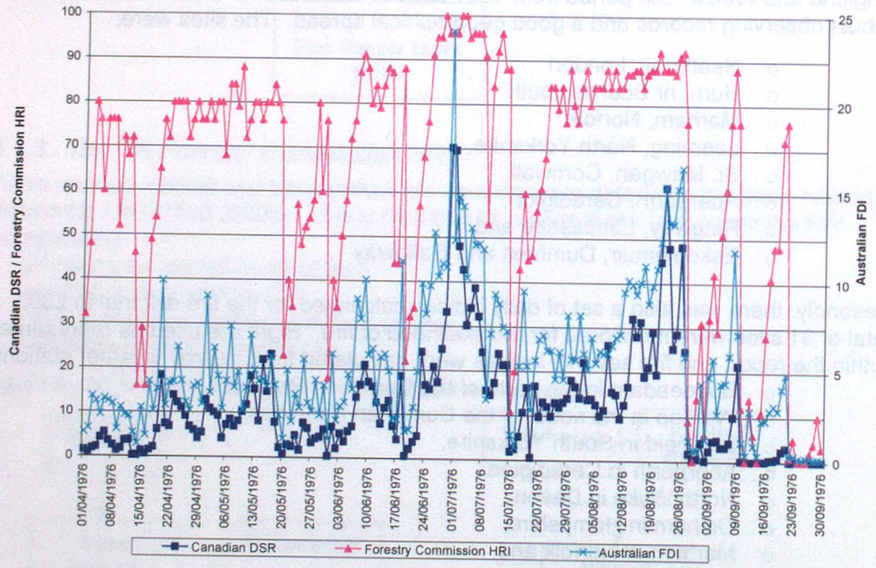
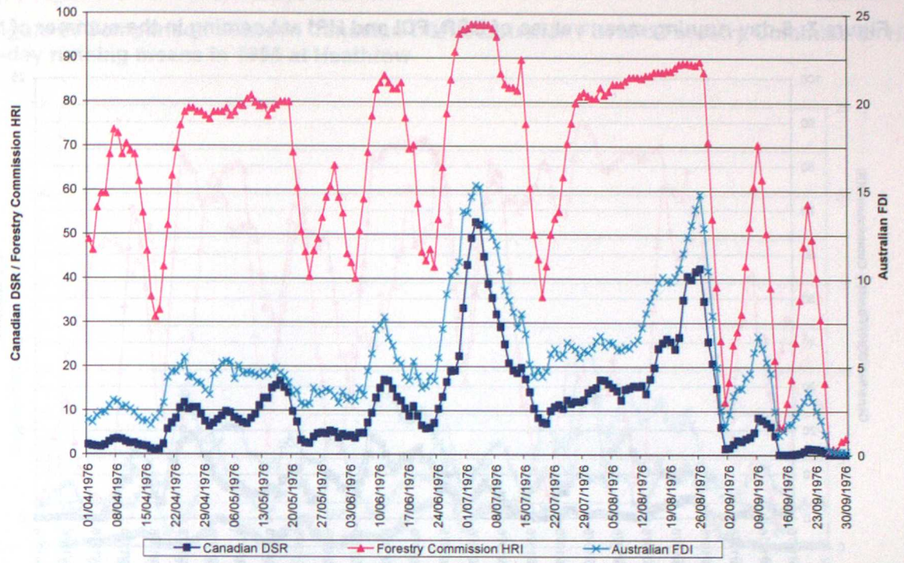


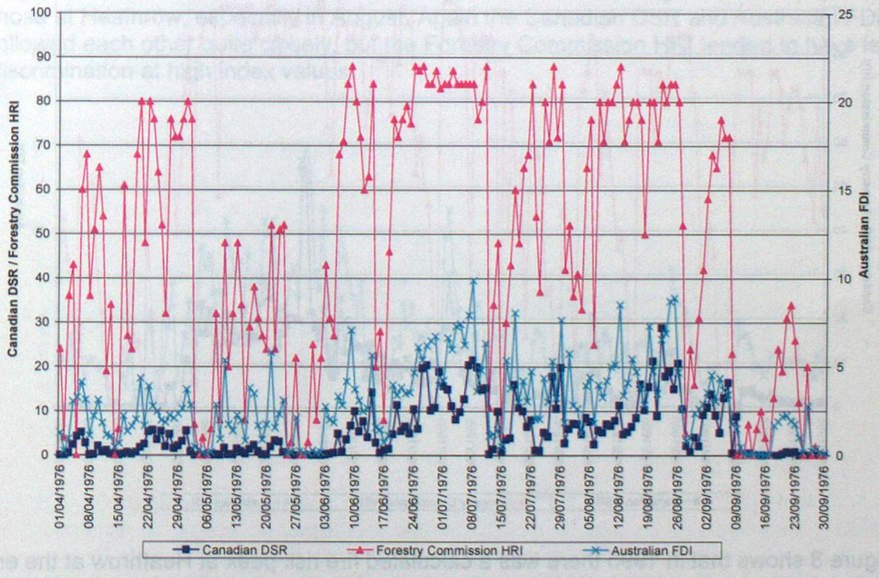
Figure 4 shows that for Heathrow there are two major peaks of calculated fire severity, one in late June/early July and a second later in August. The Canadian DSR and the Australian FDI easily pick out the two peaks and in general follow similar patterns. The HRI is quite different. This index is at a high risk level (>95) for several days, but shows little discrimination at picking out peaks as reflected by the other two indices.

Figure 5: Comparison between DSR, FDI and HRI: 5-day running means in 1976 at Heathrow



In Figure 5 the curves are smoother because each value is a mean of 5 daily values. This shows the gradual build up to the peaks, especially the second one in August. The curves for DSR and FDI are very similar. The HRI curve is again less good at differentiating between exceptional conditions and generally high risk periods, particularly at the end of August.

Figure 6: Daily values of DSR, HRI and FDI at Leeming in 1976



Figures 6 and 7 show that there are two major peaks at Leeming in early July and towards the end of August. This is similar to the pattern at Heathrow except that the Leeming values are much less than for Heathrow. The Canadian DSR and Australian FDI indices

are similar, but again the Forestry Commission HRI shows little discrimination of peak values.

Figure 7: 5-day running mean values of DSR, FDI and HRI at Leeming in the summer of 1976

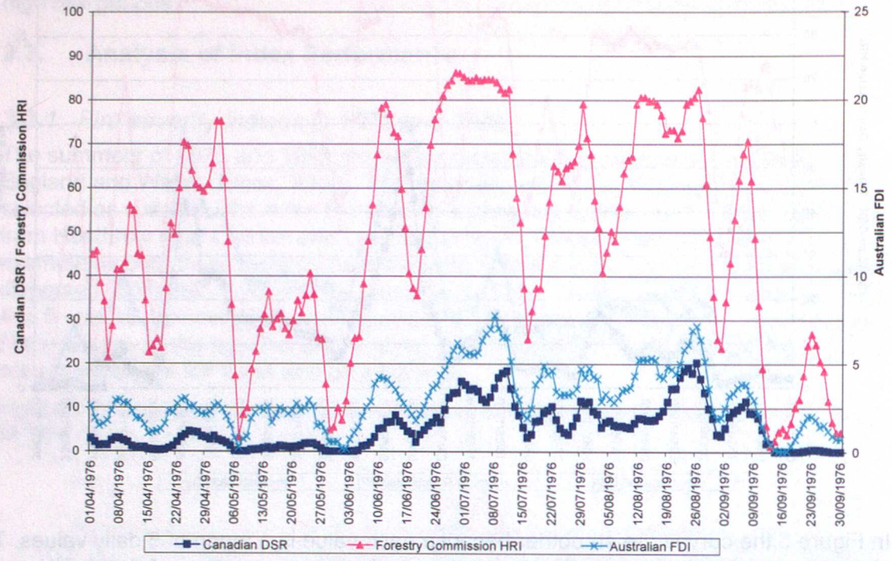


Figure 8: Comparison between Canadian DSR, Forestry Commission HRI and Australian FDI daily values in the summer of 1995 at Heathrow

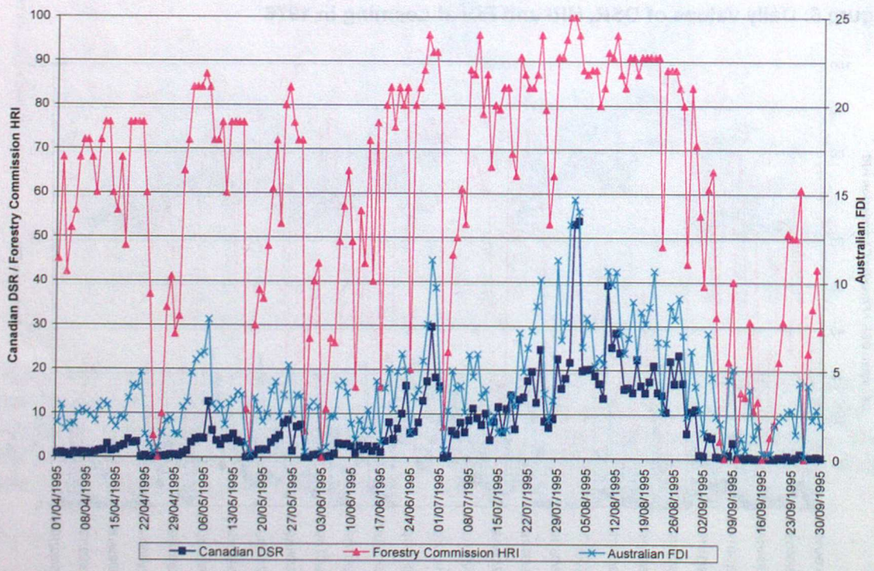
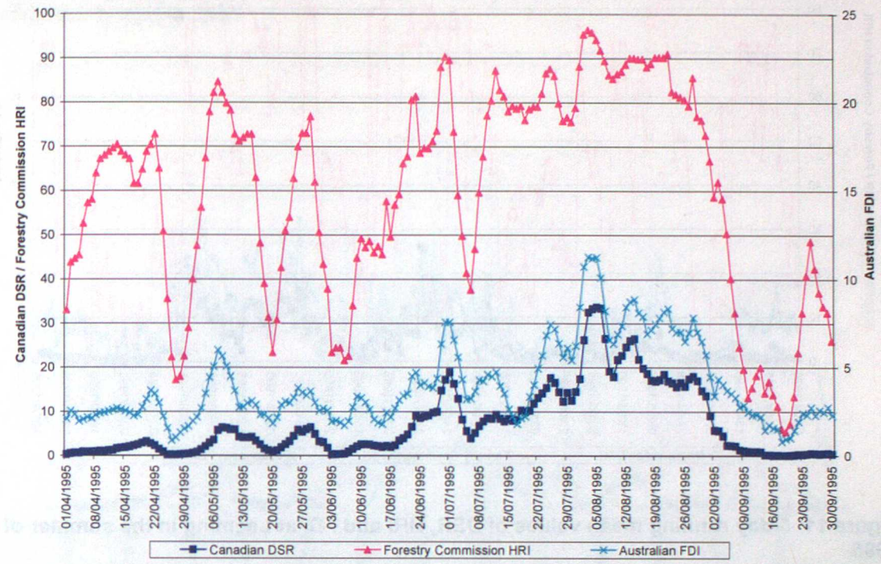


Figure 8 shows that in 1995 there was a calculated fire risk peak at Heathrow at the end of June/early July, but it was not as great as a second maximum which occurred in August. The Canadian DSR and Australian FDI again followed each other quite closely

and the Forestry Commission HRI was less good at distinguishing peaks because it was at a high level for several days at a time.

Figure 9: Comparison between Canadian DSR, Australian FDI and Forestry Commission HRI 5-day running means in 1995 at Heathrow



Again the gradual build up of the 5 day running mean to the peaks is more obvious for the Canadian DSR and Australian FDI than for the Forestry Commission HRI.

Figures 10 and 11 show data for 1995 at Leeming. There were peaks of fire risk in early July and towards the end of August. The index values at Leeming were mainly less than those at Heathrow, especially in August. Again the Canadian DSR and Australian FDI followed each other quite closely, but the Forestry Commission HRI tended to have less discrimination at high index values.

Figure 10: Daily values of DSR, HRI and FDI at Leeming in the summer of 1995

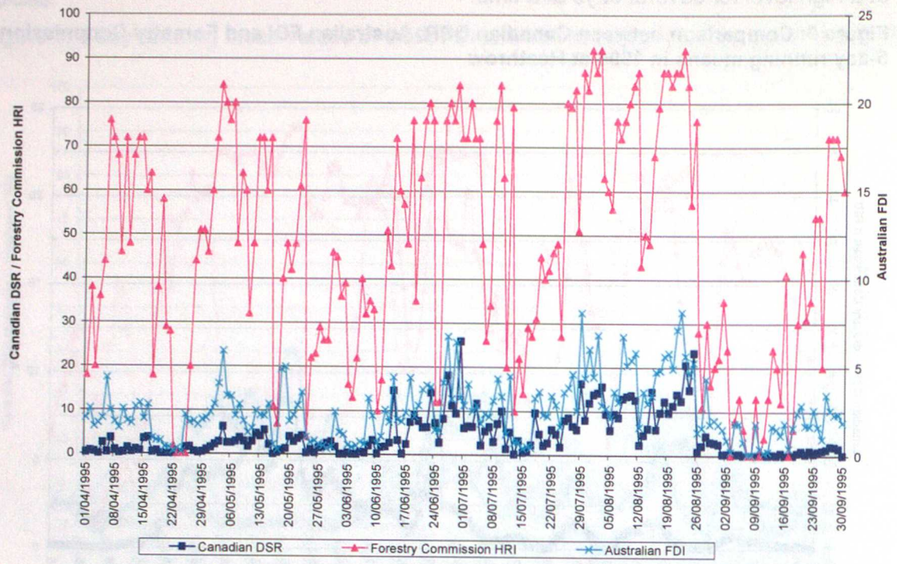
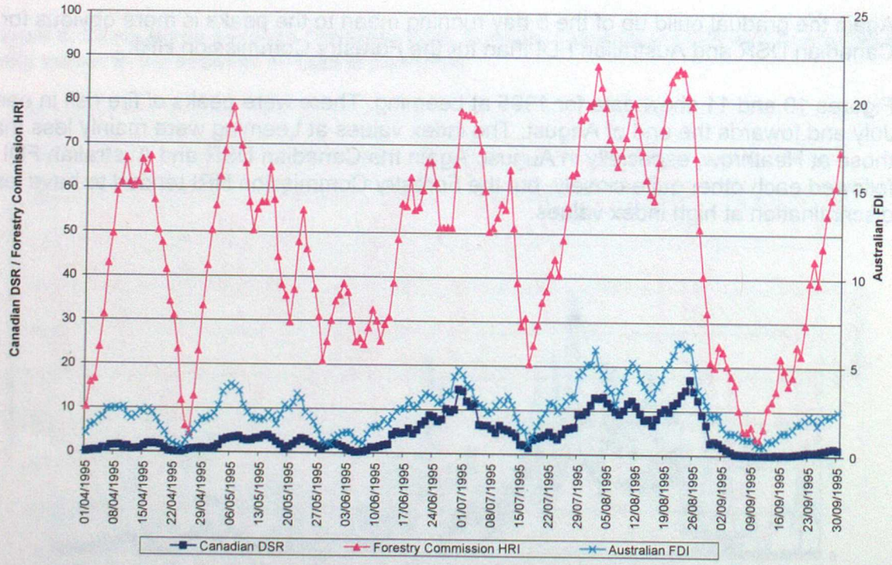


Figure 11: 5-day running mean values of DSR, HRI and FDI at Leeming in the summer of 1995



3.3.2. *Fire risk in Spring 1980*

In April and May of 1980 large parts of England and Wales experienced spells of dry weather accompanied by high temperatures and prolonged sunshine. In April warm and sunny conditions were recorded during the middle of the month with London and Manchester recording highs of 21°C on 13th April. This was followed by windy conditions and lower temperatures with some thundery showers at the end of the month. May was mainly dry with a prolonged hot and sunny spell from 9th to 19th. These two months

therefore will provide a good test for investigating whether the indices can identify risk due to a combination of weather conditions following a warm period rather than a severe drought as may be expected later in the summer. Figures 12 to 15 show the index values for this period for Heathrow and Leeming as examples.

Figure 12: Daily values of Canadian DSR, Forestry Commission HRI and Australian FDI at Heathrow in spring 1980

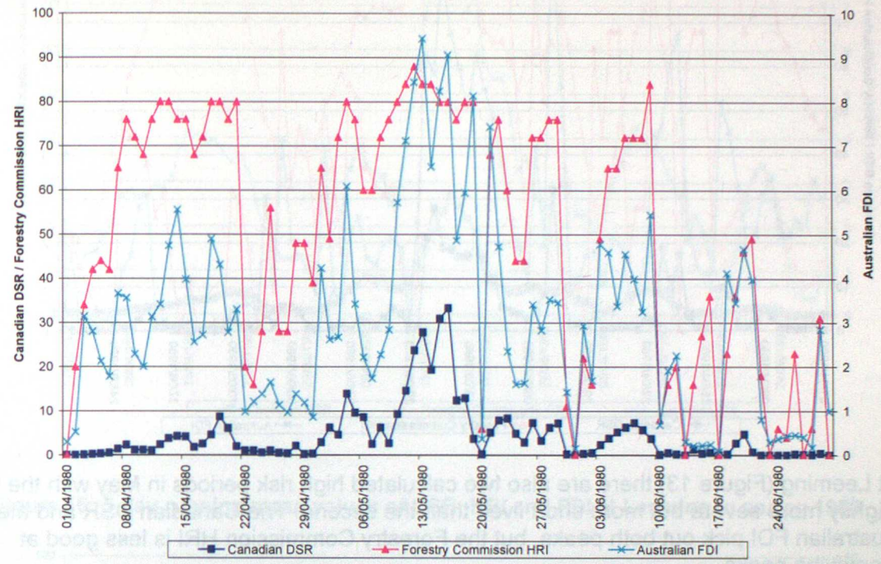
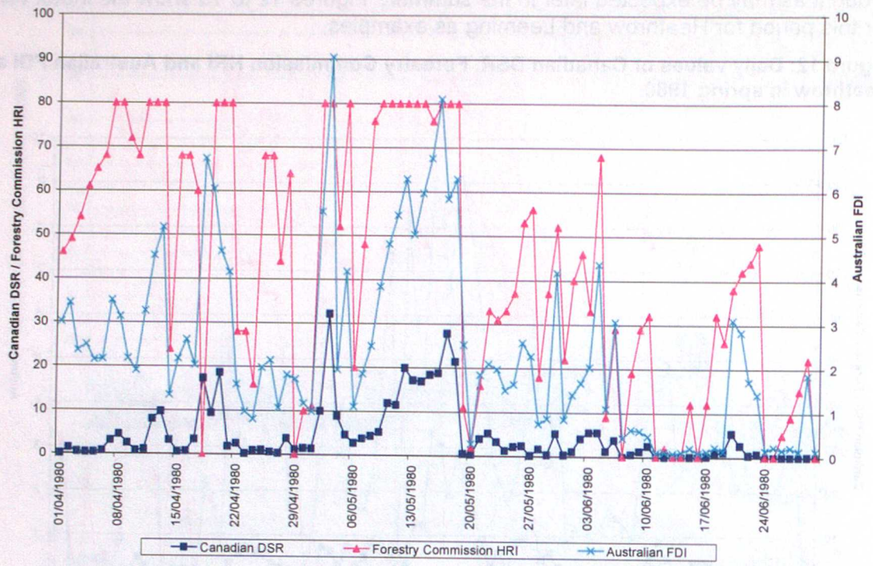


Figure 12 shows two calculated high risk periods in early and mid May identified by the Canadian DSR and Australian FDI, but the Forestry Commission HRI suggests moderate to high risk most of the time.

The Canadian DSR has a greater range than the Australian FDI (which is shown on the right hand axis) and so places more emphasis on the peaks. For example in mid May the Canadian DSR increases from about 2.7 prior to the high risk period to a peak of 33.3 which is an increase by a factor of 12.3. The Australian FDI increases from about 1.7 prior to the peak to a peak value of 9.4 which is an increase by a factor of 5.5, less than half of the increase in Canadian DSR.

Figure 13: Daily values of Canadian DSR, Forestry Commission HRI and Australian FDI at Leeming in spring 1980



At Leeming (Figure 13) there are also two calculated high risk periods in May with the first slightly more severe but more short lived than the second. The Canadian DSR and the Australian FDI pick out both peaks, but the Forestry Commission HRI is less good at identifying peaks.

Again the Canadian DSR places more emphasis on the peaks. For example in early May the Canadian DSR increases from about 1.4 prior to the high risk period to a peak of 32.1 which is an increase by a factor of 23. The Australian FDI increases from about 1 prior to the peak to a peak value of 9 which is an increase by a factor of 9, less than half of the increase in the Canadian DSR.

Figure 14: 5-day running mean values of DSR, HRI and FDI at Heathrow in spring 1980

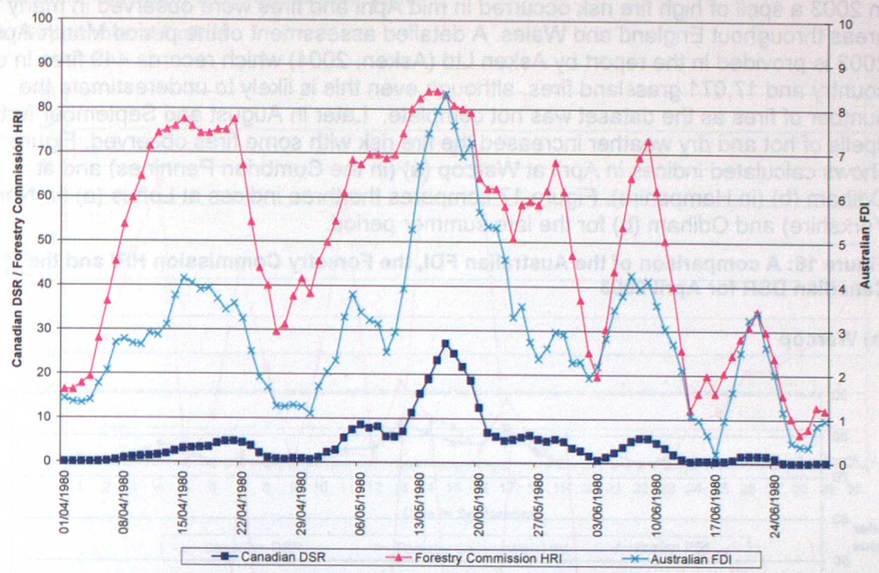
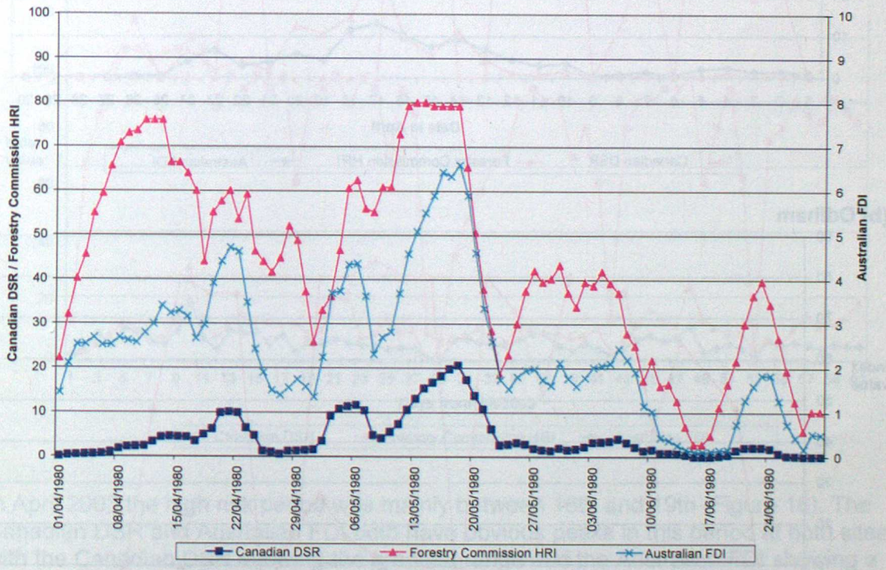


Figure 15: 5-day running mean values of DSR, HRI and FDI at Leeming in spring 1980



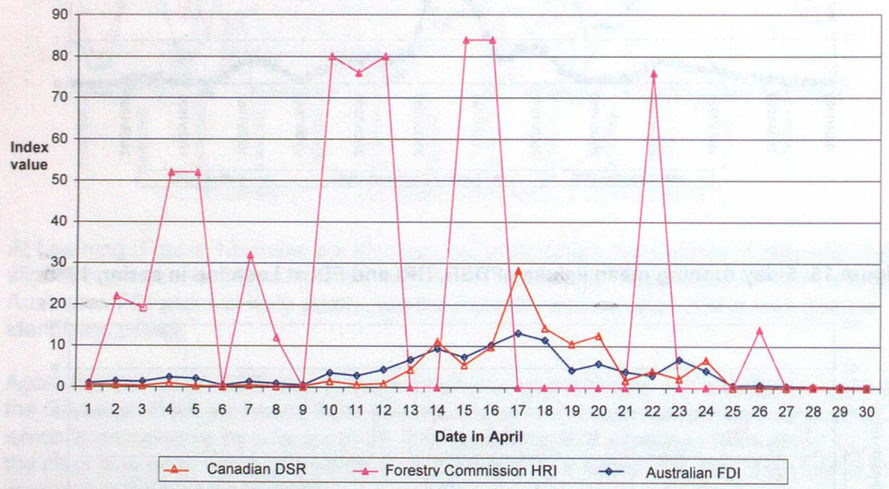
In Figures 14 and 15 the 5 day running mean curve picks out the periods of high risk in May, but the curves are smoother than the daily value curves in Figures 12 and 13. The Forestry Commission HRI peak is very broad while the Canadian DSR and Australian FDI peaks are more distinct.

3.3.3. A comparison of indices in 2003

In 2003 a spell of high fire risk occurred in mid April and fires were observed in many areas throughout England and Wales. A detailed assessment of the period March-April 2003 is provided in the report by Asken Ltd (Asken, 2004) which records 449 fires in open country and 17,071 grassland fires, although even this is likely to underestimate the number of fires as the dataset was not complete. Later in August and September further spells of hot and dry weather increased the fire risk with some fires observed. Figure 16 shows calculated indices in April at Warcop (a) (in the Cumbrian Pennines) and at Odiham (b) (in Hampshire). Figure 17 compares the three indices at Loftus (a) (in North Yorkshire) and Odiham (b) for the late summer period.

Figure 16: A comparison of the Australian FDI, the Forestry Commission HRI and the Canadian DSR for April 2003

(a) Warcop



(b) Odiham

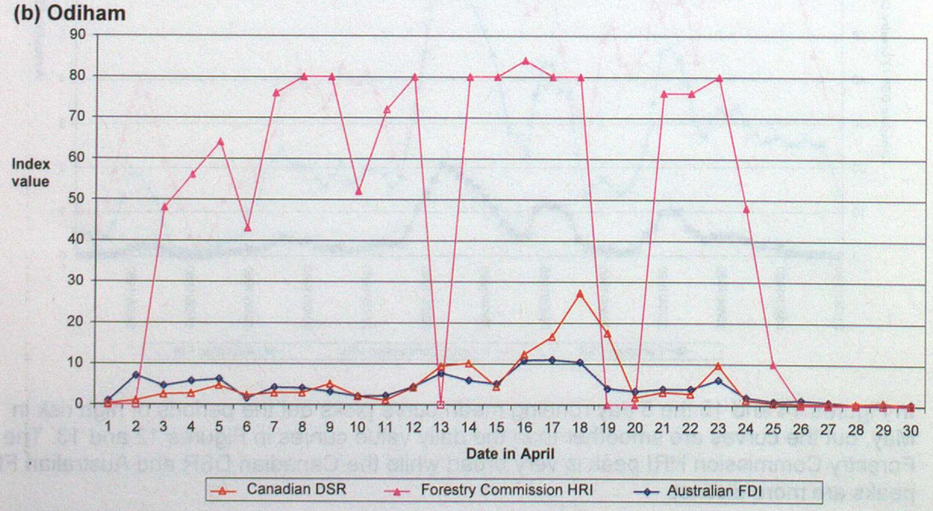
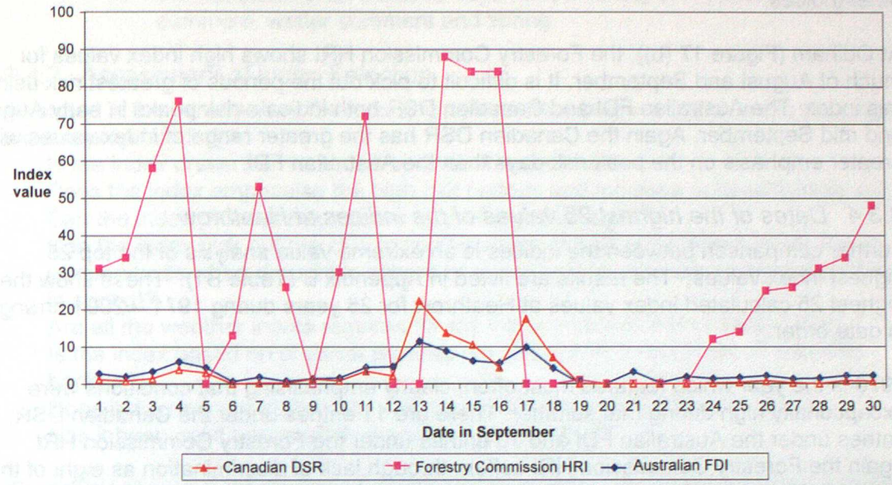
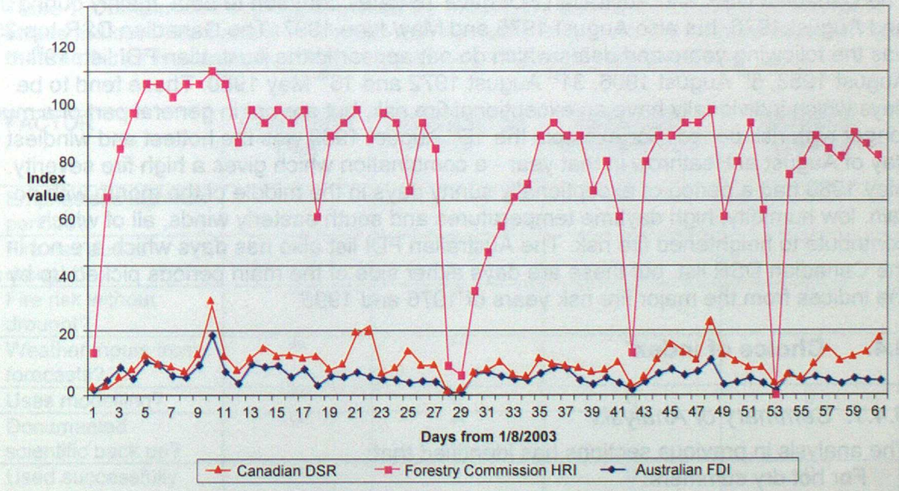


Figure 17: A comparison of the Australian FDI, the Forestry Commission HRI and the Canadian Canadian DSR for summer 2003

(a) September at Loftus



(b) August and September at Odiham



In April 2003 the high risk period was mainly between 16th and 19th (Figure 16). The Canadian DSR and Australian FDI both have obvious peaks in this period at both sites with the Canadian DSR showing the greatest range and the Australian FDI showing a flatter peak. The Forestry Commission HRI picks out several high risk periods in April, which have similar index values, and shows less discrimination than the other indices. At Warcop on 17th the Australian FDI and Canadian DSR have the maximum value for the month, but the Forestry Commission HRI missed this high risk day and instead gave a zero rating. In the Asken (2004) report, the number of Cumbrian grassland fires recorded peaks slightly earlier on the 12th, 14th and 15th April. Although this is the date when the fires started, it is not when the greatest risk occurred.

At Loftus in September the high risk spell is mid-month (Figure 17 (a)). The Canadian DSR and Australian FDI both have high index values with the Canadian DSR showing a greater range of index values. The Forestry Commission HRI does indicate a peak though a zero value is shown for the 13th and 17th which were high risk days according to the other indices.

At Odiham (Figure 17 (b)), the Forestry Commission HRI shows high index values for much of August and September. It is difficult to pick out the periods of greatest risk using this index. The Australian FDI and Canadian DSR both indicate risk peaks in early August and mid September. Again the Canadian DSR has the greater range of index values with greater emphasis on the peak risk days than the Australian FDI.

3.3.4. Dates of the highest 25 values of the indices at Heathrow

Further comparison between the indices is an extreme value analysis of the top 25 highest index values. The results are listed in Appendix B (Table B1). These show the highest 25 calculated index values at Heathrow for 25 years during 1971 – 2001 arranged in date order.

1976 is the year which features most often, clearly emphasising that conditions were exceptionally high during that summer. There are 11 entries under the Canadian DSR, 16 entries under the Australian FDI and 10 entries under the Forestry Commission HRI. Again the Forestry Commission HRI suffers through lack of discrimination as eight of the entries in the table all have a value of 100 and the remaining 17 entries were all 96. This suggests a lack of sensitivity within the index.

The Canadian DSR and Australian FDI have 16 dates common to both, mainly during July and August 1976, but also August 1975 and May/June 1997. The Canadian DSR top 25 has the following years and dates which do not appear in the Australian FDI list: 19th August 1983, 5th August 1996, 31st August 1972 and 16th May 1980. These tend to be days which individually have an exceptional fire risk, but are not in general part of a much longer high risk period. For example the 19th August 1983 was the hottest and windiest day of August at Heathrow in that year - a combination which gives a high fire severity. May 1980 had a period of exceptionally sunny days in the middle of the month with no rain, low humidity, high daytime temperatures and south easterly winds, all of which contribute to heightened fire risk. The Australian FDI list also has days which are not in the Canadian DSR list, but these are days either side of the main periods picked up by all the indices from the major fire risk years of 1976 and 1995.

3.4. Choice of index

3.4.1. Summary of Analysis

The analysis in previous sections has identified that:

- For hot dry summers:
  - the Forestry Commission HRI has poor discrimination and suggests high risk for much of the time. This would be at odds with the concept of defining an 'exceptional' event which by definition would be fairly rare and could potentially result in closing access land unnecessarily;
  - the Canadian DSR and Australian FDI are both good at picking out the peaks of greatest risk.
- For spring:
  - the Forestry Commission HRI shows lower discrimination than the other indices and tends to show broad spells of enhanced risk;
  - the Canadian DSR shows well defined peaks of risk emphasised by a greater index range than the Australian FDI.
- From the highest 25 risk dates at Heathrow:

  - the Forestry Commission HRI has the same index value for several dates. It is difficult to say which dates were more severe than others;
  - the Australian FDI emphasises drought situations with the list including more days from hot, dry summers than the Canadian DSR;
  - the Canadian DSR includes days from a variety of fire risk situations: dry summers, wetter summers and spring.

3.4.2. Assessment of Index Selection

As stated in the introduction, the following criteria were deemed important in deciding the most appropriate index:

- Is the index drawn from a sound scientific base of evidence?
- Does the index emphasise the high risk periods and increase noticeably/dramatically?
- Can the index pick out risk caused by prolonged drought?
- Can the index pick out risk due to combinations of high winds/low humidity/warm temperatures when drought is absent or not severe (particularly important for fire risk in spring)?
- Are all the weather inputs required for the index available from forecast data?
- Is the index based on physical process modelling with a documented scientific backup?
- Does it discriminate statistically well against observations of fire severity?
- Has it been used successfully elsewhere in the world?

The table below is a simple way of comparing the indices against these criteria although it must be considered in conjunction with the more detailed analysis above. No weightings have been applied to any of the criterion.

Table 1: Comparative scoring of suitability factors for the DSR, FDI, HRI and MORECS stress indices. The symbol '' means that the factor is shown to a marked degree, '*' means that the factor is shown to a slight or moderate degree, '0' means absent.**

FACTOR	CANADIAN DSR	AUSTRALIAN FDI	FORESTRY COMMISSION HRI	MORECS STRESS
Emphasises high risk periods?	**	**	*	*
Fire risk due to drought?	**	**	**	**
Fire risk without drought?	**	*	*	0
Weather inputs from forecasts?	**	**	**	*
Uses modelling?	**	0	0	0
Documented scientific back up?	**	**	*	*
Used successfully internationally?	**	*	0	0
TOTAL STARS	***14***	***10***	***7***	***5***

Table 1 shows that MORECS and the Forestry Commission HRI index have the lowest scores and the choice is between the Canadian DSR and the Australian FDI. The Australian FDI performs well under most circumstances, but it tends to emphasise drought situations. It is less good at emphasising the fire risk in spring before drought has built up, or in summers without severe drought.

The modelling of the fuel moisture content which forms part of the Canadian DSR gives it a distinct advantage over other indices and it is more sensitive, particularly in terms of identifying risk from a range of different weather scenarios. The Australian FDI is more relevant to Australian conditions, where severe drought is the main concern.

The differences in the weighting given to drought are connected with the make up of the indices. A major part of the Australian FDI index is a drought factor. The highest FDI values are in major drought years, but high risk spells in less droughty summers, or in spring before drought has built up, are given less weight. The Canadian DSR includes a drought factor, but places greater emphasis on short term risk due to high winds and low humidity than the Australian FDI. These short term conditions are an important consideration in England and Wales.

This means that the Canadian DSR can give high risk to drought summers, but it is better than the Australian FDI at emphasising other occasions of risk especially in spring. The Forestry Commission HRI index tends to switch from low to high risk depending on current and past rainfall. Once the Forestry Commission HRI is indicating high risk, further discrimination based on wind speed, for example, is more subdued. This does not incorporate the condition of land element as strongly as in the other indices which assess the longer term weather impact on the land.

Woodland and forest protection agencies in several countries have chosen the Canadian system to aid in the control of fires. It is in use in Mexico through work by the North American Forest Commission (http://fms.nofc.cfs.nrcan.gc.ca/Mexico/), New Zealand (Valentine, 1978) and Portugal among others. In New Zealand it was introduced in 1980 because the Canadian system was then recognised as being soundly based on underpinning research with outstanding interpretive backup and because of some similarities of climate. The Canadian system has also recently been adopted in Portugal where it is used to organise fire fighting in a national park (Rainha and Fernandes, 2002).

It is therefore proposed that the Canadian DSR index is the most appropriate for identifying exceptional conditions in England and Wales. Prior to making a firm recommendation the following sections further test this choice by considering:

- whether the Canadian index is applicable to a range of vegetation types
- how well the DSR compares to the observational trial conducted during 2003

3.4.3. Application of the Canadian DSR to different types of vegetation

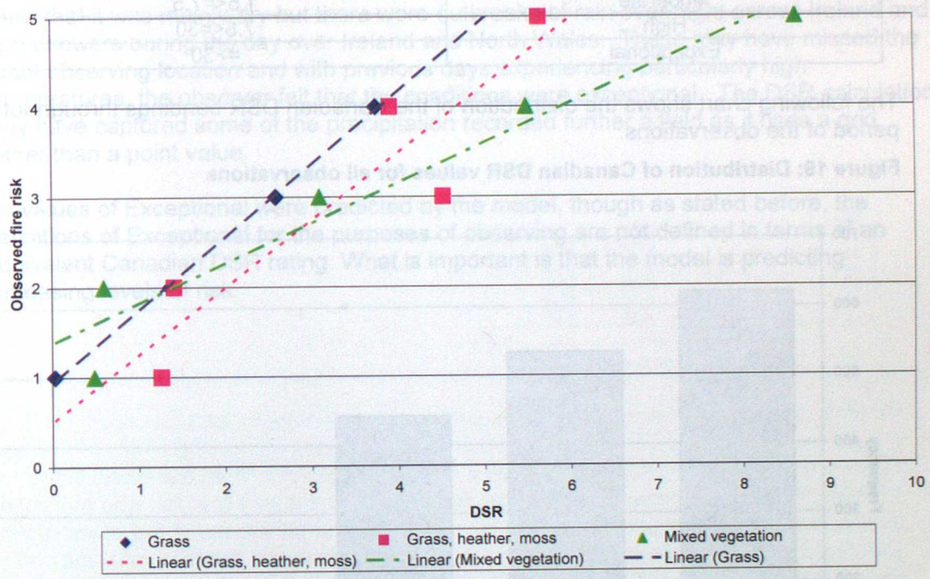
The Canadian DSR index was originally developed for areas covered with coniferous forests and it is based on data for the rates of burning of pine needles, litter etc. However different fuel types burn at varying rates and so absorb moisture differently. Therefore the initial spread of the fire and other characteristics will differ depending on the vegetation. This is not a specific issue for the Canadian index but would arise for any chosen index developed on a specific set of land use conditions. It is recommended that the index is used in conjunction with other information about the land and that the methodology continues to be tuned for conditions which are common to England and Wales to ensure that it is suitable for identifying risk across different vegetation types.

Analysis of trial results for 2003 has been carried out when fire risk was assessed by observers for different vegetation types, and this gives some confidence that the Canadian index is applicable across different vegetation types. Of the twenty sites with data, two had grass only, three had a combination of grass, heather and bog mosses and seven had a mixed type which was composed of grass, heather, bracken, bog mosses, deciduous and coniferous trees. The observers were asked to assess fire risk on the scale of 1 (Nil), 2 (Low), 3 (Moderate), 4 (High) and 5 (Exceptional). A comparison of the daily Canadian DSR ratings with the observed fire risk for the mixed vegetation types shows that there is a clear increase with the observed fire risk, especially for observed values above 2, although there is also some scatter. Some of the reasons for the scatter in the daily values include the variation of individual site factors such as the presence of water

near to the ground surface. The Canadian DSR was not, in general, calculated for the actual site (but the nearest weather station) so that differences in rainfall between the site and the weather station for example could introduce systematic bias and scatter.

In Figure 18 the mean Canadian DSR for the observed fire risk categories has been plotted for the different vegetation types. In general there is an increase in the Canadian DSR as the observed fire risk increases. There is also a tendency, at the highest two observed fire risks, for the mean DSR for the sites with grass only or with grass, heather and bog moss to be lower in comparison to sites with mixed vegetation. This supports the suggestion that the perceived fire risk is higher for vegetation with a high proportion of grass than it is for one which includes trees.

Figure 18: Mean DSR index corresponding to the observed fire risk in 2003 at sites with grass only, those with grass, heather and bog moss and those with mixed vegetation including trendlines



Hence the Canadian DSR can be used to assess risk for different vegetation types.

3.4.4. Performance of the DSR against 2003 Trial Data

The following analyses how the Canadian DSR performs against the 2003 trial data which was collected from a number of observation sites across England and Wales. It compares the Canadian DSR values with the predicted bandings monitored by observers on the ground. There are a number of factors to be considered in terms of interpreting the analysis:

- Whilst every effort was made to ensure that there was consistency amongst the observers by providing explanatory notes there are inevitably some discrepancies due to the differing interpretations of risk.
- The risk reported by the observers is not related to the risk scale of the Canadian DSR. The trial observations were initiated before this model was selected and therefore care should be taken not to necessarily compare an 'exceptional' observed value against the corresponding exceptional class for the Canadian DSR
- It was not possible to complete an analysis on each individual site for which observations were available as the sample size for some sites was too small to draw

significant conclusions from. This was also due to the limited period for collecting observations and the intermittent nature of the observations throughout that period. Therefore, results for all of the observation sites have been combined to provide a dataset with 1,722 observations in total from 31 sites. If every observation had been recorded over the 6 month period, a total of 5,859 would have been expected. Therefore the trial collected 29% of the potential number of observations possible.

For ease of analysis the Canadian DSR values have been organised into the following bands which, although not matching the proposed class bandings to be used operationally, (see Chapter 6) do provide a good spread of DSR values:

Table 2 : Class bandings used for comparison of Canadian DSR against observations

Monitored Risk	Canadian DSR Value
Very low	0<=0.2
Low	0.2<=1.5
Moderate	1.5<=7.5
High	7.5<=30
Exceptional	=>30

The following chart shows the distribution of the Canadian DSR bandings throughout the period of the observations.

Figure 19: Distribution of Canadian DSR values for all observations

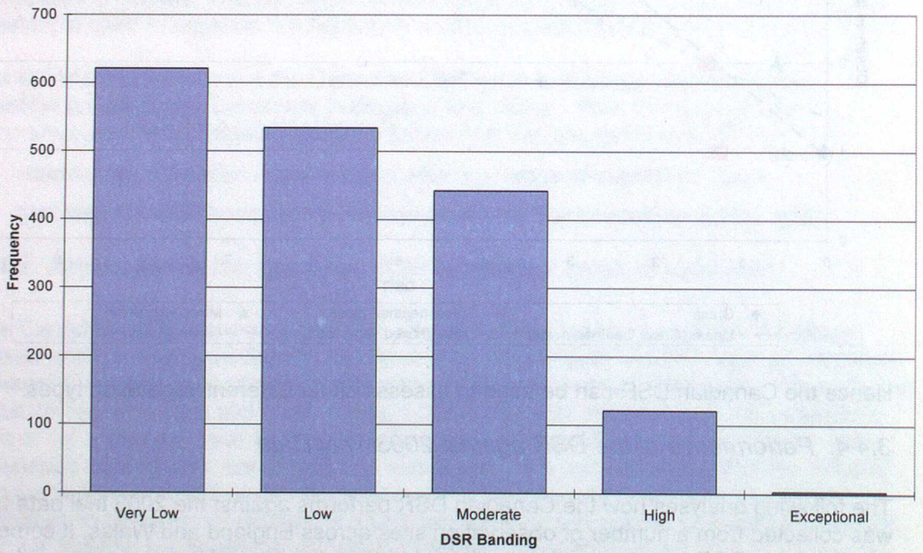


Figure 19 shows that only a very small number of cases with a value of 30 or more were calculated, comprising only three predictions out of the total 1,721 cases. It also demonstrates that the vast majority of results lie within the first three classes.

Figure 20 illustrates the change in distribution as different levels of fire severity are recorded by observers. It shows that when an observed value of Very Low was monitored on the ground, the Canadian DSR generally also indicated the most of the results to lie within the lowest range. A total of 97% of model results also lie within the first three bands (Very Low to Moderate). However, on one occasion the Canadian DSR predicted an Exceptional value, even though Very Low risk was observed. This occurred on the 12th June near the Powys, Shropshire and Herefordshire border, and our records show that although it was mostly dry and sunny across the country, scattered showers did occur

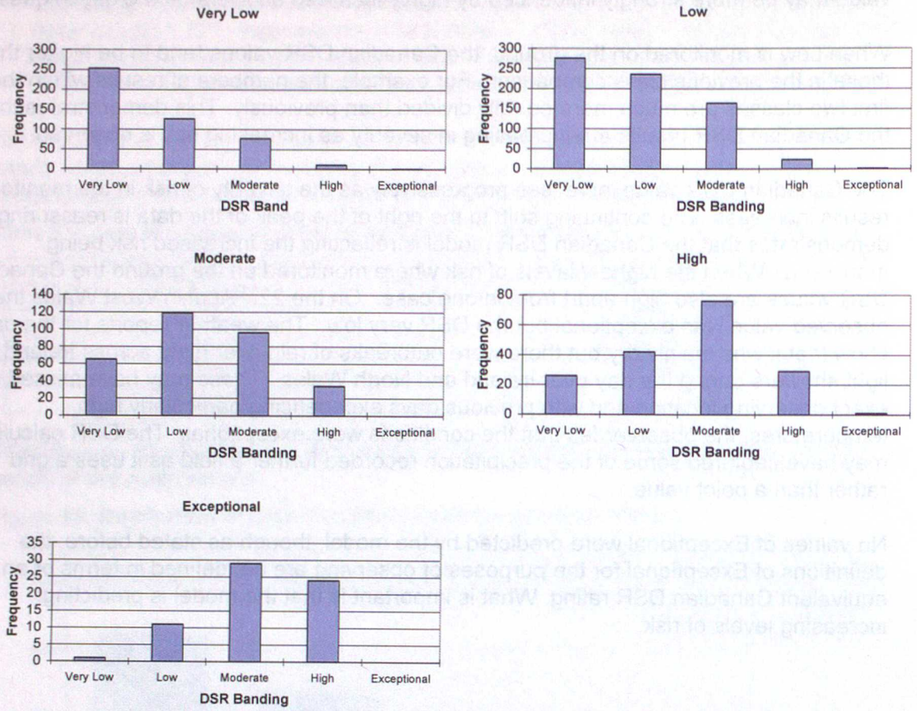
across Wales and Northern England during the morning and early part of the afternoon. Previous good weather may contribute to the build up of the DSR whereas the observed value may be more strongly influenced by highly localised showers on the day in question.

When Low is monitored on the ground, the Canadian DSR values tend to be higher than those in the previous class comparison. For example, the numbers of results within the first two classes are much more equally divided than previously. This demonstrates that the Canadian DSR results are increasing in severity as increasing risk is observed.

The Canadian DSR value increases progressively as the severity of risk in the monitored results increases. The continuing shift to the right of the peak of the data is reassuring and demonstrates that the Canadian DSR model is reflecting the increased risk being monitored. When the highest levels of risk where monitored on the ground the Canadian DSR values are also high apart from in one case. On the 22nd April in West Wales the observed value was exceptional but the DSR very low. The weather reports for the day show that it was mainly dry but there were outbreaks of rain over night across Ireland and light showers during the day over Ireland and North Wales. These may have missed the exact observing location and with previous days experiencing particularly high temperatures, the observer felt that the conditions were exceptional. The DSR calculation may have captured some of the precipitation recorded further a field as it uses a grid rather than a point value.

No values of Exceptional were predicted by the model, though as stated before, the definitions of Exceptional for the purposes of observing are not defined in terms of an equivalent Canadian DSR rating. What is important is that the model is predicting increasing levels of risk.

Figure 20: Canadian DSR values when Very Low / Low / Moderate / High / Exceptional conditions were observed



Whilst a direct comparison between each class of observations and Canadian DSR results cannot be made, it is clear that the model provides increasing levels of risk as the observations also demonstrate increased risk on the ground. In an extremely small number of cases, an extreme value was predicted whilst a very low risk was monitored. This is likely to have been due to very localised weather conditions at the observation site which were not reflected in the weather recording taken some distance from the observation site, but which was used for the model predictions. A localised shower can have a significant effect on the likelihood of fire risk: a problem common to any choice of fire index. It is therefore important to use forecast rainfall data at the maximum spatial resolution available to capture as much as possible of this local behaviour. The trial data has proved very useful in ensuring that the Canadian DSR model behaves in a realistic manner.

3.4.5. Conclusion

Based on the requirements stated in Chapter 1, the Canadian DSR index is therefore recommended as the most appropriate fire severity index for the types of weather conditions and vegetation common to England and Wales. Its strengths are that:

- it is good at picking out periods of greatest risk in hot, dry summers, wet summers and springtime;
- it has a strong basis of scientific evidence underpinning its development;
- it is more sensitive than other indices as it has a greater value range, highlighting both specific peaks and gradual increases in risk;
- it is able to identify fire risk from a range of different weather scenarios;

- it can be used to assess risk for different vegetation types;
- it is used successfully outside Canada.

4. Exceptional Conditions

4.1. Introduction

One of the key objectives of a fire severity index is to indicate periods of exceptional risk to inform the decision making process of other agencies. This chapter identifies the DSR values above which fire risk can be considered exceptional, and tests the proposed critical value against known rare events.

It uses a combination of recorded observational data from Met Office climate records and also data based on local assessments of conditions during 2003. There is a risk in using index values calculated from observational weather data to identify a threshold. This is because there may be a bias in the computer model generated weather data which is the data source for the operational forecast fire risk system. DSR values derived from observed data are used in Section 4.3 to test any suggested values. Values derived from model data are examined in more detail in chapter 5.

4.2. Identifying a Critical Value to Assess Severe Risk

4.2.1. Methodology

This section considers the question of whether a single value for the DSR index can be found throughout England and Wales to indicate the most severe risk periods. This will be investigated using evidence from:

- the years 1976 and 1995 which were particularly hot;
- the 2003 fire risk trial period;
- dates of fires at Canford Heath (Dorset) identified from the Asken report.

These data will be used to identify whether there is some critical value which would capture periods of severe fire risk regardless of geography or location. The choice of such a value is inevitably subjective to some degree but the analysis helps to highlight the type of events and circumstances which such a value should capture, and tests whether an appropriate threshold can be identified.

4.2.2. Evidence from 1976 and 1995

1976 and 1995 experienced exceptionally hot weather conditions and therefore any viable index should show particularly high fire index values for these periods. A review of the 1976 drought by the editor of Weather Eye magazine for the BBC noted that

> "The drought and great heat combined to provide the ideal conditions for the propagation of heath and forest fires ….. The county of Dorset was typical of the serious situation throughout England and Wales with fires breaking out on a daily basis".

In the years 1976 and 1995 the maximum index values at the same 8 climate stations as considered in Chapter 3 are listed below.

Table 3: Maximum values of the DSR index calculated at 8 weather stations for 1976 and 1995

Site	1976	1995
Aberporth (Ceredigion)	111.5	35.6
Eskdalemuir (Borders)	9.4	15.7
Heathrow (London)	70.2	53.8
Hurn (Dorset)	54.0	35.5
Leeming (N Yorks)	28.8	25.8
Marham (Norfolk)	43.8	-
Ringway (Manchester)	50.0	36.1
St. Mawgan (Cornwall)	49.7	57.3

The value of 111.5 at Aberporth in 1976 is the highest value for the eight stations in any of the available years between 1971 and 2001 and was due to high temperatures accompanied by strong winds. Heathrow had the next highest index value in 1976 and several others had values of around 50. The values for Eskdalemuir (9.4) and Leeming (28.8) were lowest overall. The drought was less severe in northern areas than further south, but also Eskdalemuir in particular is set within a large forestry area which reduces windspeeds and hence reduces the index values.

In 1995 several stations have index values between 30 and 50 with an average value of 37.11. Again Eskdalemuir and Leeming are lower than the others. However:

- exceptional station values can vary widely. Exposed coastal sites and those at airfields can have higher wind speeds and hence higher index values than more sheltered inland locations.
- places in areas with a warm summer climate with low humidity (Heathrow) generally have higher index values than places in the west and north.

The results for 1976 and 1995 suggest that a daily value of DSR above 30 would pick out the worst periods and locations in those summers. The following sections test the hypothesis that 30 is a good critical value above which to define conditions as severe or exceptional.

4.2.3. Evidence from 2003

In April 2003 fires were especially widespread in England and Wales with areas of unmanaged grassland, moorland and heath particularly affected. This was associated with weather patterns characterised by high pressure over the Baltic and south easterly winds over the UK. Conditions were especially sunny with high daytime temperatures and low humidity in western areas. Values of the DSR index are available for the 31 sites which were included in the observational trial of 2003 and Table 4 shows maximum values of DSR, when above 15, for each day between 15th and 24th April.

Table 4: Values of the DSR index above 15 for the high fire risk period in April 2003 for the trial sites

Date in April 2003	DSR value	Location
13	15.3	Aberporth
16	15.3	Marham
17	28.3	Leeming
	16.6	Odiham
	18.7	Marham
	28.3	Warcop
18	27.2	Odiham
	15.1	Marham
19	22.8	Aberporth
	17.5	Odiham
21	16.5	Aberporth

In Table 4 the highest values ranged between 15 and 28.3. These are rather exceptional figures for April, but less than values in the summers of 1976 and 1995. To judge the exceptional nature of these figures the previous maximum recorded values of the April DSR for 1971-2001 are given in Table 5.

Table 5: Maximum values of DSR in April for 8 sites from years between 1971 and 2001

Site	Maximum April DSR value	Year
Aberporth	9.3	1987
Eskdalemuir	13.1	1971
Heathrow	18.3	1976
Hurn	20.3	1984
Leeming	18.6	1980
Marham	13.3	1996
Ringway	8.7	1974
St. Mawgan	40.4	1984

The St. Mawgan value in Table 5 is higher than any value in April 2003, but most of the others were equalled or exceeded in 2003. This clearly indicates the severe and widespread nature of the April 2003 event from weather station data at 8 sites around England and Wales. A daily 'critical' index value of around 20 would capture this event.

4.2.4. Evidence from Canford Heath fires

Data was provided by Poole Borough Council and Dorset Fire and Rescue Service for Canford Heath near Poole, Dorset for dates of fires observed between 1991 and 2001. Canford Heath is an urban fringe area particularly liable to fires being started deliberately.

Dates of observed fires are compared with the calculated DSR index from Hurn which is the nearest observing site, 13.2 kilometres to the north east. The median and upper quartile values of DSR have been found for the days with a reported fire as follows:

1. The DSR on the day of a reported fire is noted.
2. These values are ranked.
3. The median and upper quartile values are found.

The results are shown in Table 6. For each month the median and upper quartile value of the index obtained from the full set of monthly maxima of DSR for 1971-2001 is given for comparison in Table 6.

Table 6: Values of the DSR index calculated for Hurn on the same days as observed fires on Canford Heath, Dorset 1991-2001. In each month the median and upper quartile values are shown.

	1991/2001 Hurn Fire Days		1971-2001 Long Term Averages	
	Median	Upper Quartile	Median	Upper Quartile
April	0.9	2.2	4.4	5.8
May	1.5	2.6	10.2	11.6
June	4.0	5.8	10.4	13.8
July	6.0	8.4	13.5	20.2
August	13.0	15.2	11.7	20.7
September	4.0	5.4	5.5	9.1

Table 6 shows that for days where fires were reported there is a seasonal increase of DSR index from April to August with a decrease in September. It is possible to have a fire with a wide range of index from low values in April (median 0.9) to high values in August (13.0). In some months, especially April, fires were reported on days with an index value of zero. Table 6 also shows that fires took place at index values largely below the long term median or upper quartile values. For example in April the median index on days with fires is 0.9 which is much less than the median index (4.4) based on the maxima from all Aprils.

These results confirm that there is no absolute value of DSR below which a fire cannot occur. Canford Heath is an urban fringe area which experiences a lot of deliberate fires. Table 6 shows that fires can occur in nearly all weather conditions if sufficient effort is made. However, months with higher index values tend to experience more frequent and larger fires. For example in 1995 nearly all days with fires had a DSR of greater than 9.

4.2.5. Summary

It is clear that weather conditions for exceptional fire risk can start abruptly especially as a spell of warm, breezy weather arrives. This is particularly the case in spring when the soil can be moist, but the parts of plants above ground are dry.

The daily index is more appropriate than the 5-day running mean to indicate the start of a high risk period because the 5-day mean has a more subdued peak which can mask a single high risk day. The end of a high risk period is less easy to define, but if the daily index value has dropped to a low level for several days after a high risk spell then the fire risk is clearly reduced. This could be due to heavy rain soaking the ground and vegetation which will cause an immediate drop in fire risk, but it can also be due to a drop in wind speed and temperature.

The main findings in this chapter are that :

- a daily DSR value above 30 would capture exceptional fire risk periods in the hot summers of 1976 and 1995 for areas most likely to be at risk;
- a lower value is needed in spring, illustrated by analysis of the period of exceptional fire risk recorded in April 2003;
- evidence from Canford Heath demonstrates that it is not possible to predict the actual occurrence of fires as, particularly in urban areas, these can occur at any time of year in any conditions if someone is motivated enough to start a fire.

As well as the analysis above, there is scientific evidence for seasonal variation with regard to the nature of fires and hence the associated risk. In summer both the weather and the ground conditions are likely to be hotter and drier and so fires are likely to be more deep-rooted. In the spring or autumn it is more likely that whilst the ground is wet, dry vegetation may result in flash fires across the surface. Therefore it is reasonable to use different thresholds for exceptional fire risk in summer and in spring/autumn.

The following suggests a definition of the start and end of exceptional periods, capturing both the proposed critical value and the seasonal variation identified:

Exceptional periods start when:

- in summer the daily index exceeds 30, or
- in spring and autumn the daily index exceeds 20.

In summers with severe drought a higher index is indicated as compared with spring or autumn. This is related to the greater degree of drying of the land in summer drought compared with spring when the material below the surface can still be moist. In autumn the soil tends to wet up from the top downwards so that much of the surface fuel is moist although it can dry out rapidly as dead vegetation and leaf litter can not draw moisture from the ground. This supports the implementation of a lower exceptional rating in autumn.

4.3. Testing the choice of threshold against historical events

4.3.1. Methodology

The purpose of this section is twofold:

1. to assess whether the DSR values proposed for exceptional conditions are representative of the top end of the actual index values of the last 30 years
2. to assess whether the threshold DSR values would adequately indicate when fire risk was exceptional compared to known high risk periods.

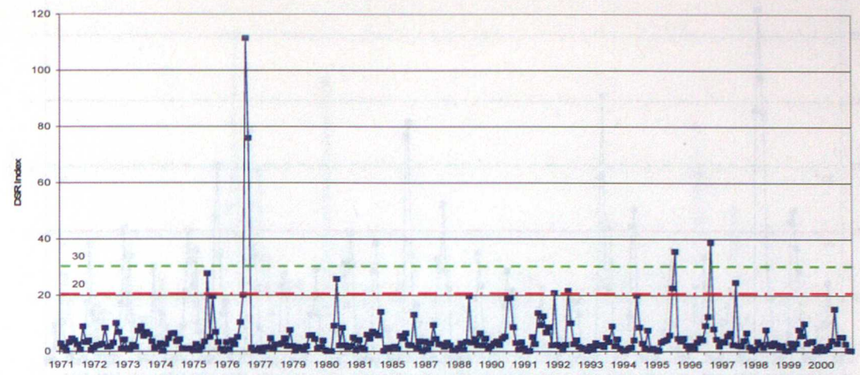
This is assessed by analysing the eight stations with the most complete historical records over the last 30 years and which give a good geographic distribution, and by specifically considering the 2003 period when fire risk was known to be high.

4.3.2. Historical monthly maxima of DSR

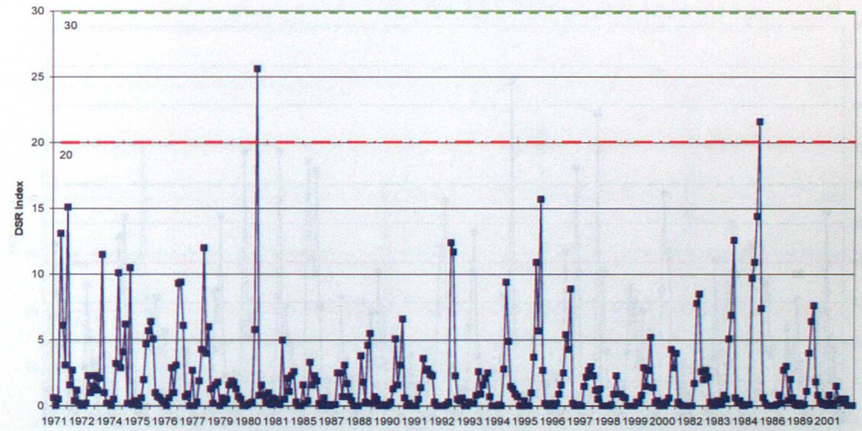
In order to assess how frequently exceptional conditions in the past would have been identified based on the threshold values stated above, data for the 8 sites used in Chapter 3 with long observing records are analysed. This will assess whether the Canadian DSR values of 20 and 30 are reasonable and allow identification of periods which are known to be particularly vulnerable to fire risk such as the summers of 1976 and 1995. Figures 21 (a) to (h) plot all of the available monthly maximum values of DSR and compare them with DSR values of 20 or 30.

Figure 21: Monthly Maximum values of DSR for all available years for 8 sites

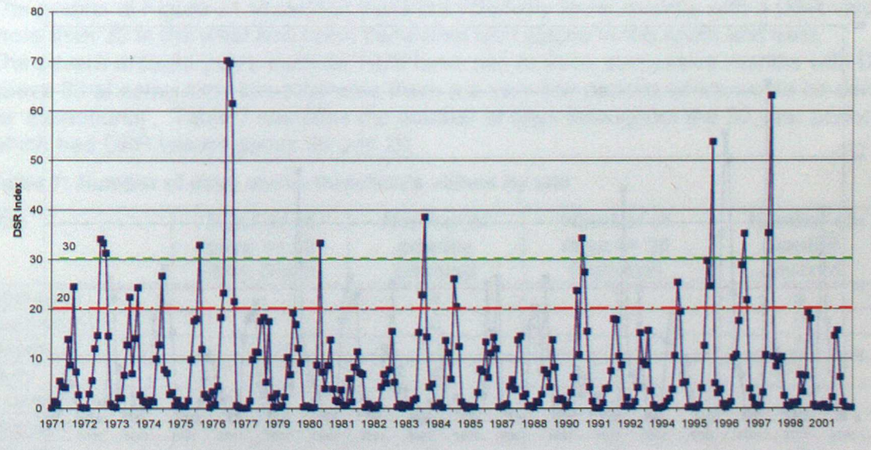
a) Aberporth (1971-2000)



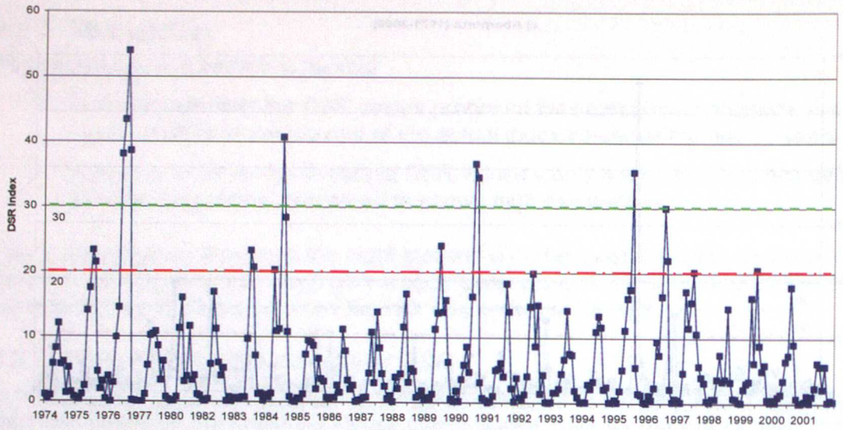
b) Eskdalemuir (1971-2001)



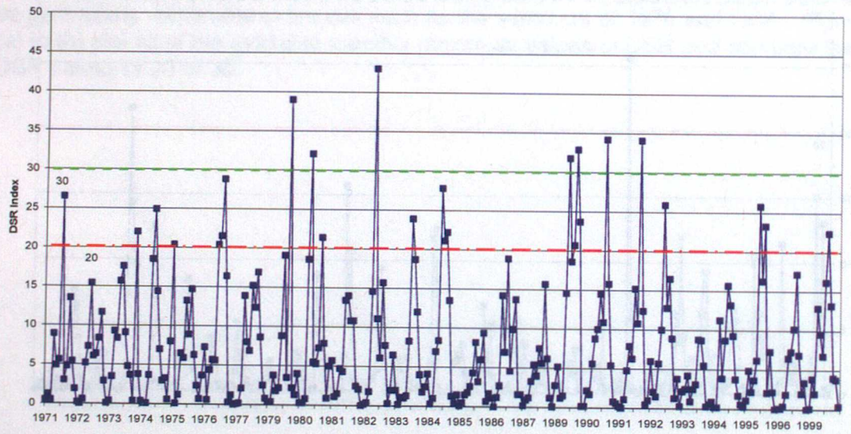
c) Heathrow (1971-2001)



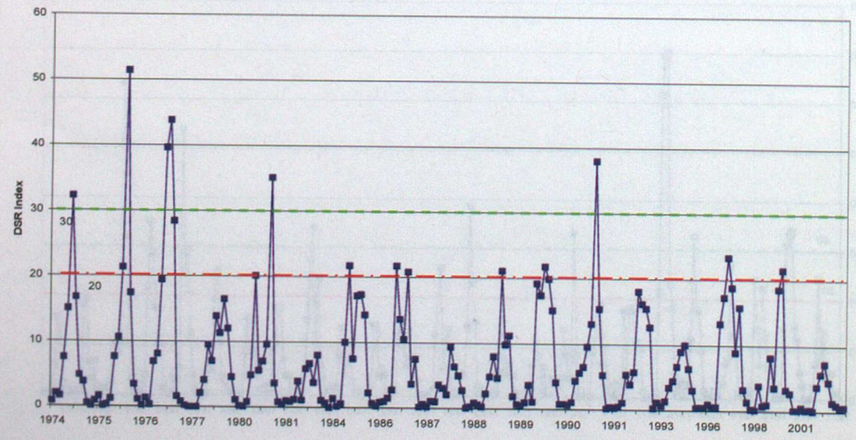
d) Hurn (1974-2001)



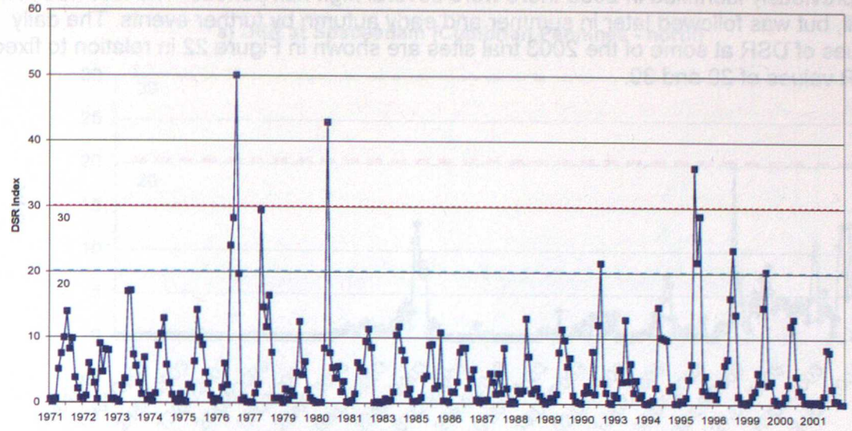
e) Leeming (1971-1999)



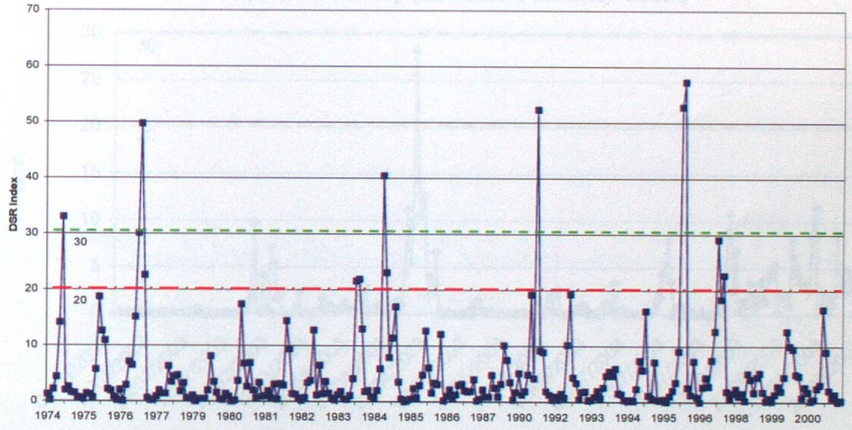
f) Marham (1974-2001)



g) Ringway (1971-1999)



h) St Mawgan (1974-2000)



The graphs at Figure 21 show that there are relatively fewer months with a DSR value of more than 30 in the west and north compared with places in the south and east.
The severe drought years such as 1976 have two or three successive months with DSR above 30 at some sites but otherwise there are very few periods which would be defined as 'exceptional'. Table 7 identifies the number of days throughout the 30 year period which had DSR values above 30 and 20.

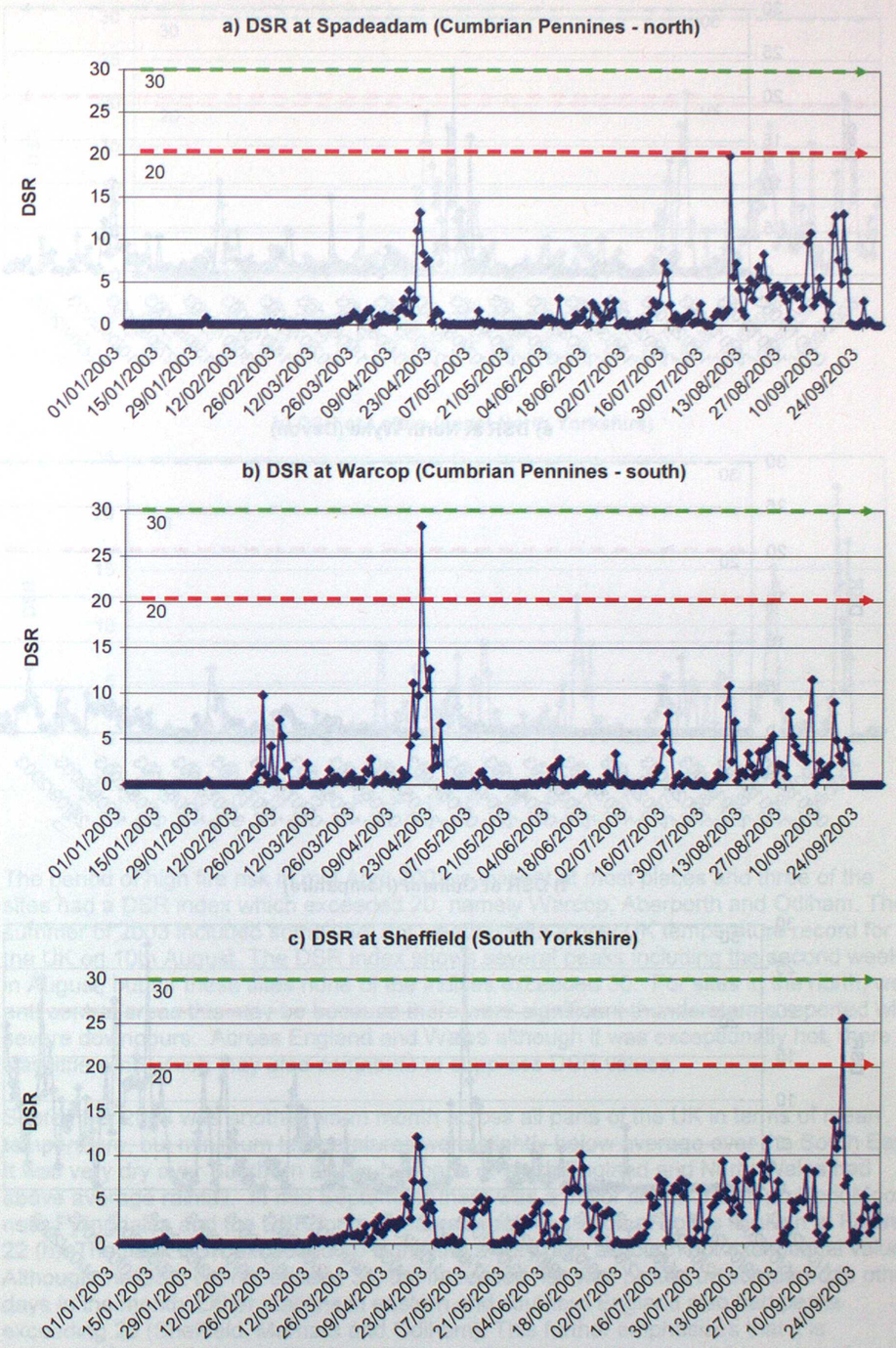
Table 7: Number of days above thresholds values by site

Site	Number of days >= 30 (May-Sept)	Number of months covered	Number of days >= 20 (Oct-Apr)	Number of months covered
Aberporth	5	4	1	1
Eskdalemuir	0	0	0	0
Heathrow	32	14	0	0
Hurn	15	9	1	1
Leeming	10	7	3	3
Marham	12	6	0	0
Ringway	10	3	0	0
St. Mawgan	9	6	2	1

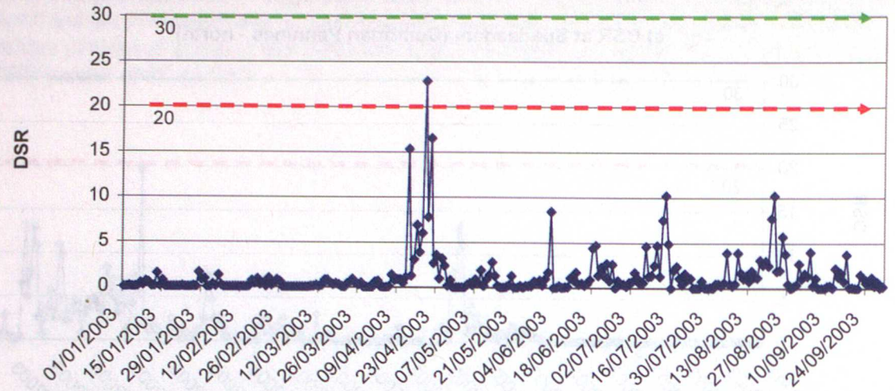
4.3.3. *The year 2003 in relation to fixed DSR values*

As previously identified in 2003 there were several high risk periods. The first was in mid April, but was followed later in summer and early autumn by further events. The daily values of DSR at some of the 2003 trial sites are shown in Figure 22 in relation to fixed DSR values of 20 and 30.

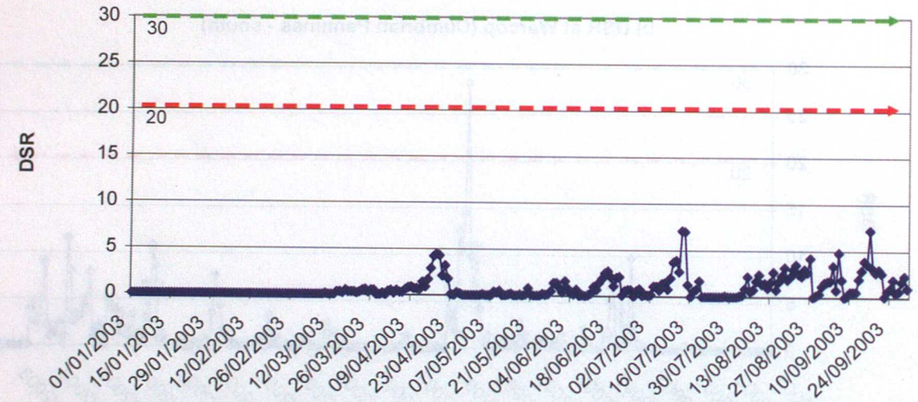
Figure 22: : Daily DSR values for 8 weather stations from January to September 2003



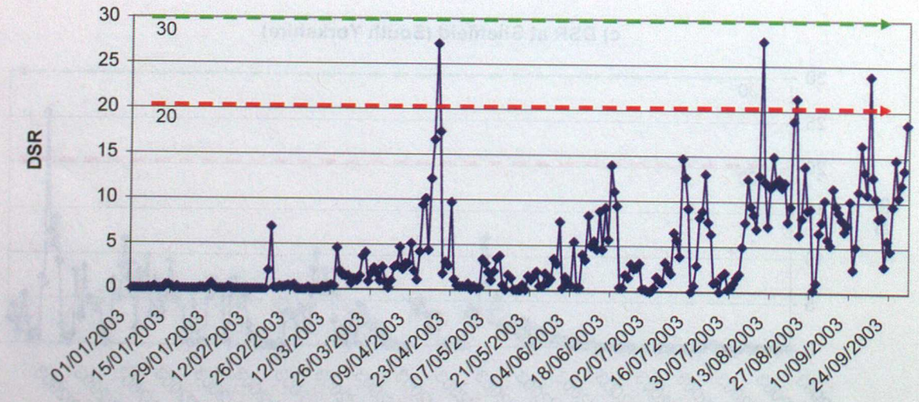
d) DSR at Aberporth (Ceredigion)



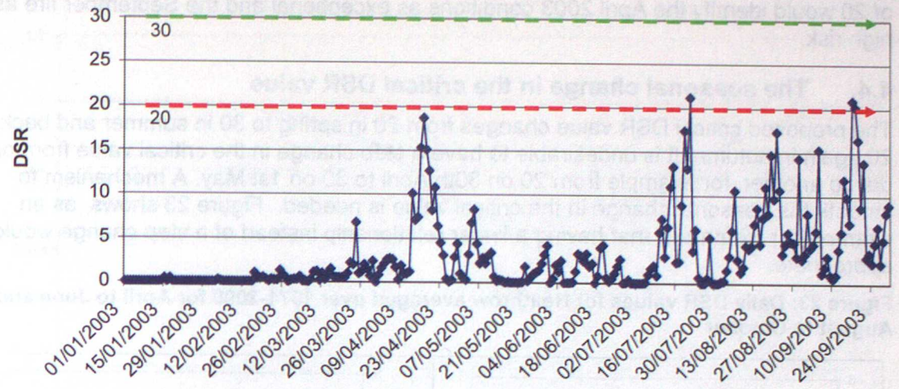
e) DSR at North Wyke (Devon)



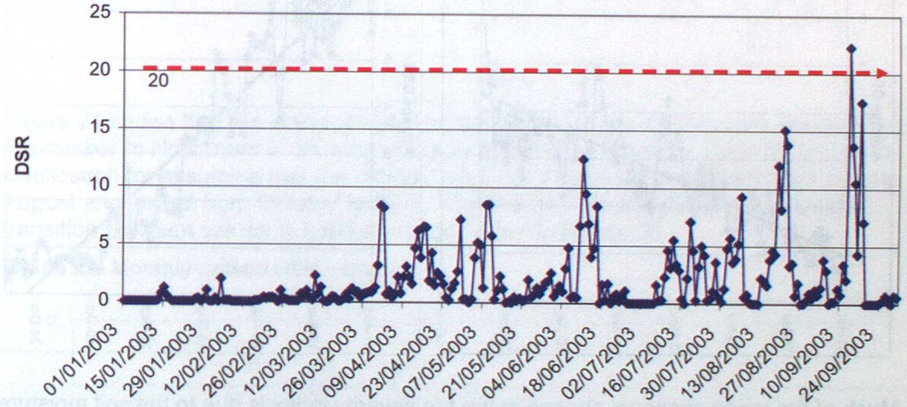
f) DSR at Odiham (Hampshire)



g) DSR at Marham (Norfolk)



h) DSR at Loftus (coast North Yorkshire)



The period of high fire risk in mid April 2003 is evident at most places and three of the sites had a DSR index which exceeded 20, namely Warcop, Aberporth and Odiham. The summer of 2003 included some very hot weather with a new UK temperature record for the UK on 10th August. The DSR index shows several peaks including the second week in August, but for these sites none of the indices exceeded 30. For sites in the north, west and central areas this may be because there were significant thunderstorms reported with severe downpours. Across England and Wales although it was exceptionally hot, there was little wind which may also contribute to suppress DSR values.

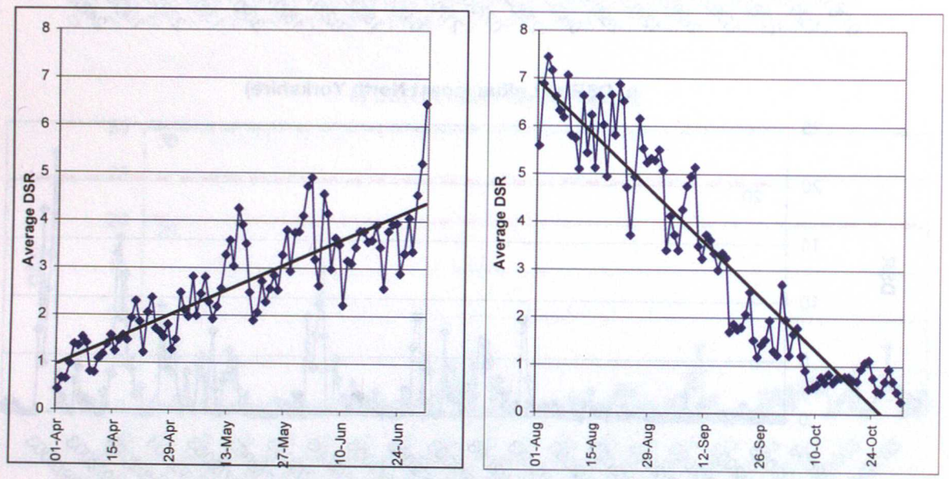
September 2003 was another warm month across all parts of the UK in terms of mean temperature, but minimum temperatures were slightly below average over the South East. It was very dry over Southern areas, but parts of North England and North Wales had above average rainfall. In mid September there was a major fire on the North York Moors near Fylingdales and the DSR for the nearest weather station at Loftus is given at Figure 22 (h). The peak DSR exceeded 20 signifying a very high although not exceptional value. Although the DSR did not exceed 30, the increased risk was picked up compared to other days in the month. Other stations in eastern and southern England also had peaks exceeding 20 (Sheffield, Marham and Odiham). This further emphasises that it is impossible to predict whether a fire will occur as this may be due to a wide range of circumstances, most likely to be instigated by human behaviour. However the increase in risk and the propensity of the fire to spread can be assessed.

In summary for 2003, both the exceptional fire risk in April and a known notable fire event in September would be identified from increases in the index. A critical value of the DSR of 20 would identify the April 2003 conditions as exceptional and the September fire as high risk.

4.4. The seasonal change in the critical DSR value

The proposed critical DSR value changes from 20 in spring to 30 in summer and back to 20 again in autumn. It is undesirable to have a step change in the critical value from one day to another, for example from 20 on 30th April to 30 on 1st May. A mechanism to smooth the seasonal change in the critical value is needed. Figure 23 shows, as an example for Heathrow, that having a linear relationship instead of a step change would be appropriate.

Figure 23: Daily DSR values for Heathrow averaged over 1971-2000 for April to June and August to October



Much of the mean seasonal change in the fire severity index is due to the soil moisture since part of the DSR index is a slowly varying drought component with other weather factors adding a more rapid day to day variation on top of this. Therefore the mean stress value (where stress is the actual evaporation divided by the potential evaporation – see Section 2.4) will be a strong contributor to the DSR value and the relationship between monthly DSR values would be expected to reflect that of monthly stress values. The variation of the mean stress by month is shown in Figure 24.

Figure 24: The monthly mean stress for rough grazing for 1961 – 2004 for MORECS squares 161 and 93

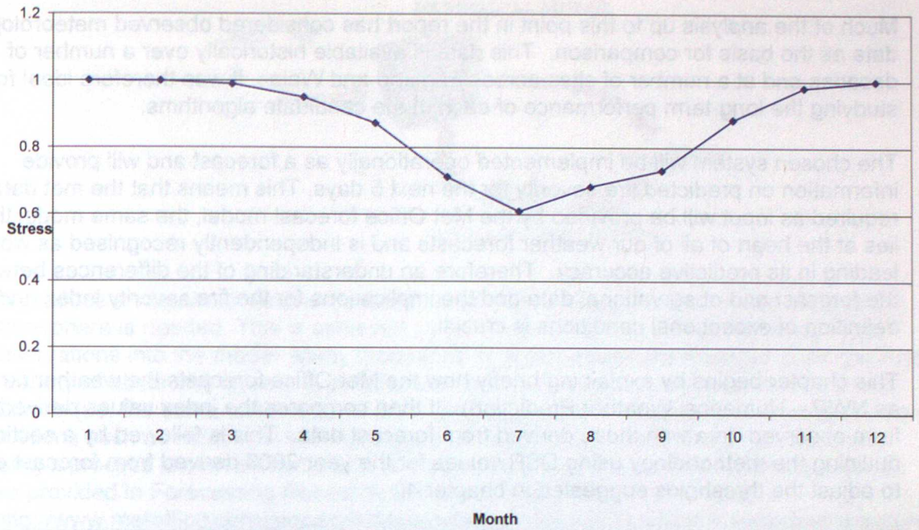
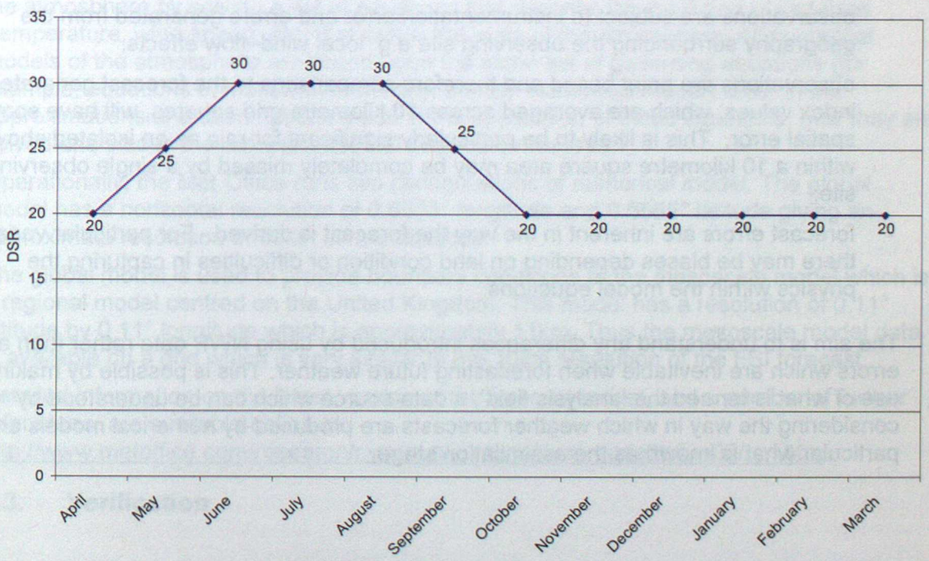


Figure 24 shows that the stress increases from April to June and similarly decreases from September to November in an approximately linear way. Figures 23 and 24 are some justification for assuming that the critical daily DSR values will be highest from June to August and lowest from October to April. The simplest relationship to describe the transition between values is a linear one as shown in Figure 25.

Figure 25: Monthly critical DSR values



In Figure 25 the values for May and September are for the mid month day. During May a linear variation from 20 on 30th April to 30 on 1st June is assumed. Also in September a linear variation from 30 on 31st August to 20 on 1st October is assumed.

5. Understanding the Effects of Using Forecast Data

5.1. Introduction

Much of the analysis up to this point in the report has considered observed meteorological data as the basis for comparison. This data is available historically over a number of decades and at a number of sites across England and Wales. It was therefore ideal for studying the long-term performance of each of the candidate algorithms.

The chosen system will be implemented operationally as a forecast and will provide information on predicted fire severity for the next 5 days. This means that the met data required as input will be provided by the Met Office forecast model, the same model that lies at the heart of all of our weather forecasts and is independently recognised as world-leading in its predictive accuracy. Therefore an understanding of the differences between the forecast and observational data and the implications for the fire severity index and the definition of exceptional conditions is crucial.

This chapter begins by explaining briefly how the Met Office forecasts the weather (known as NWP – Numerical Weather Prediction). It then compares the index values derived from observed data with those derived from forecast data. This is followed by a section outlining the methodology using DSR values for the year 2003 derived from forecast data to adjust the thresholds suggested in chapter 4.

In the following sections for clarity, DSR–Obs refers to DSR values produced from observed meteorological data and DSR-NWP refers to DSR values produced from forecast data.

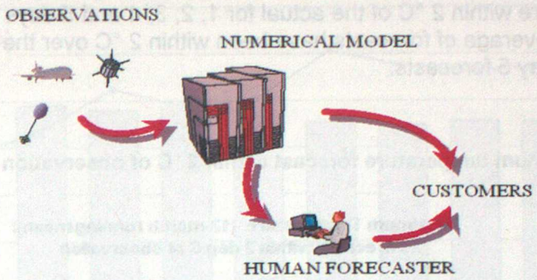
5.2. Forecasting the Weather

There are a number of known differences between forecast and observational data arising from errors in both techniques:

- observations are subject to instrumentation error and errors generated from the geography surrounding the observing site e.g. local wind–flow effects;
- observations are point based and therefore comparisons to the forecast generated fire index values, which are averaged across 10 kilometre grid squares, will have some spatial error. This is likely to be particularly significant for rain as an isolated shower within a 10 kilometre square area may be completely missed by a single observing site;
- forecast errors are inherent in the way the forecast is derived. For particular variables there may be biases depending on land condition or difficulties in capturing the physics within the model equations.

The aim is to understand any differences introduced by using NWP data rather than any errors which are inevitable when forecasting future weather. This is possible by making use of what is termed the 'analysis field', a data-source which can be understood by considering the way in which weather forecasts are produced by numerical models and in particular what is known as the assimilation stage.

Figure 26: The NWP Process



To produce an accurate weather forecast, precise knowledge of the current state of the atmosphere is needed. This is achieved by using observations and assimilating those observations into the model. Many thousands of observations are received each day from a variety of observing types e.g. satellites, aircraft, ships, buoys, radiosondes and land stations (i.e. the same observational data used previously in this study and measured at locations such as Heathrow or Ringway). Observations are assimilated into the model using a process known as variational analysis. Details of this complex analysis process are provided in Forecasting Research Scientific Paper 34 by A.C. Lorenc (http://www.metoffice.com/research/nwp/analysis/index.html) which is based on a lecture given at the Second WMO Symposium on Assimilation of Observations in Meteorology and Oceanography, held in Tokyo, Japan, 13-17 March 1995.

This analysis field, a regular grid of met data across the UK, forms the starting point for the numerical model which produces the forecast. It represents the current state of the atmosphere having blended quality-controlled observations and modelled information.

Numerical modelling is the process of obtaining an objective forecast of the future state of the atmosphere by solving a set of equations that describe the evolution of variables (temperature, wind speed, etc) that define the state of the atmosphere. All numerical models of the atmosphere are based upon the same set of governing equations (for example, equations of motion or thermodynamics). Numerical models differ in the approximations and assumptions made in the application of these equations, how they are solved and also in the representation of physical processes.

Operationally, the Met Office runs two configurations of numerical model. The global model has a horizontal resolution of 0.8333° longitude and 0.5555° latitude giving an approximate resolution of 60km in mid-latitudes.

The global model is used to provide boundary conditions to the mesoscale model which is a regional model centred on the United Kingdom. This model has a resolution of 0.11° latitude by 0.11° longitude which is approximately 11km. Thus the mesoscale model data is available on a grid which is very similar to the 10km resolution of the FSI forecast.

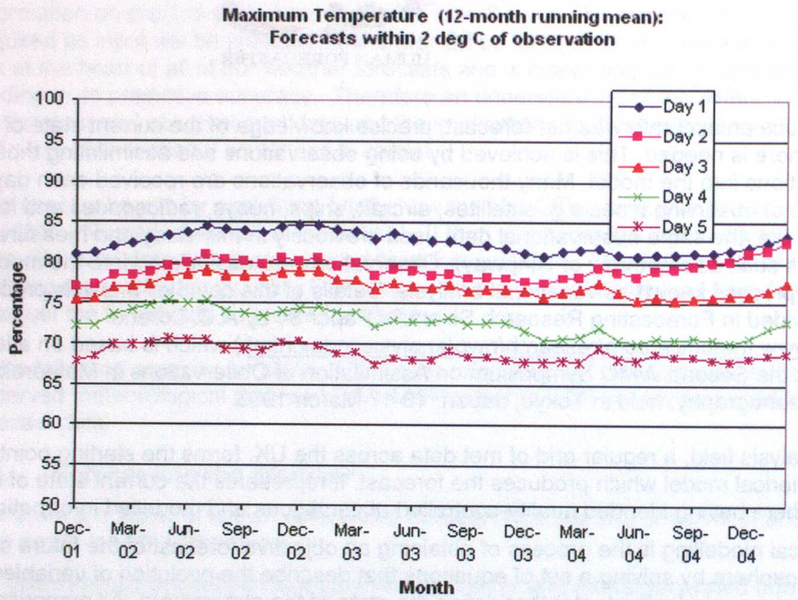
Detailed information on the latest version of the forecast model, and a number of further references, are available online at
http://www.metoffice.com/research/nwp/publications/nwp_gazette/jun02/um.htm

5.3. Verification

Forecast data is regularly verified (Met Office, 2003) against both observations and the analysis that the model produces. Verification gives an indication of how accurate the forecast is. The accuracy of the forecast depends on a number of aspects including the complexity of weather patterns involved, the accuracy of the initial analysis and how many days ahead the forecast is for. For example, a forecast for five days time will be less accurate than one for tomorrow.

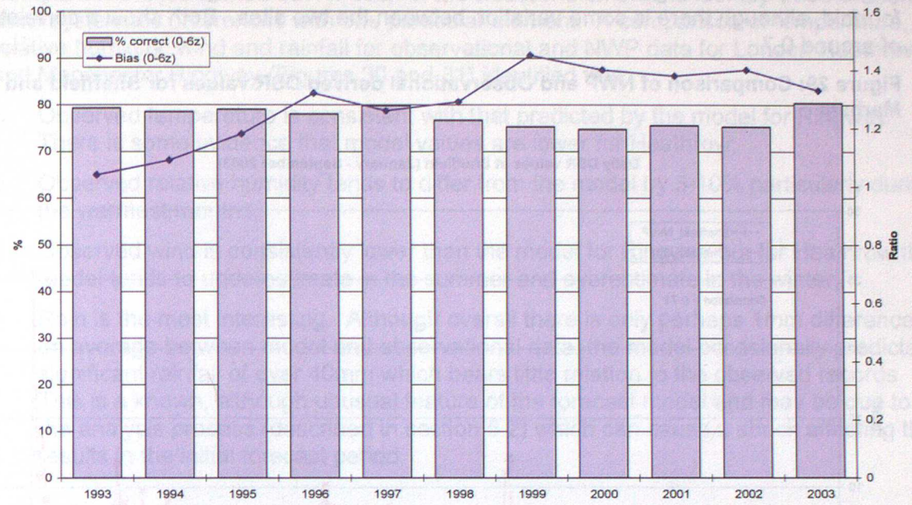
Figure 27 illustrates this for maximum temperature. The graph shows the percentage of forecasts that are within 2 °C of the actual for 1, 2, 3, 4 and 5 days ahead. For day 1, about 82% on average of forecasts have been within 2 °C over the last 4 years, falling to about 70% of day 5 forecasts.

Figure 27: Maximum temperature forecast within 2 °C of observation



For the fire severity index, the most significant meteorological variable is rainfall. Figure 28 shows two measures of the accuracy of the rain forecast by the mesoscale or short range (up to 48 hours) model. The first gives the proportion of times the model was correct in predicting whether rain occurred or not, averaged across the country. The second measure provides an assessment of the precipitation bias as a ratio of the number of occasions on which rain was forecast compared to the number of occasions on which rain was observed.

Figure 28: Verification of the Mesoscale Model (Rain)



Both of these measures focus on the first six hours of the forecast. Errors will increase as the forecast period increases. An alternative way to present the forecast is using probabilities from an ensemble of models. Over 50 different models can be run based on slightly different initial conditions and the results used to construct a probability distribution. From this, the likelihood of a particular forecast can be given with a probability rating to indicate the confidence in this scenario occurring. The use of ensemble forecasting will be explored in the next stage of the project.

Further information on NWP can be found at
http://www.metoffice.gov.uk/research/nwp/index.html
Further details on verification can be found at
http://www.metoffice.gov.uk/corporate/verification/city.html.

5.4. Comparing DSR-Obs and DSR-NWP Values

Data was considered for the period between January and September 2003. Observed data relates to the eight sites around the country used in previous chapters, whilst DSR-NWP values were derived for every 10km gridpoint across England and Wales. The two were matched by comparing a site value with one from the corresponding grid square covering that site. Comparisons included:

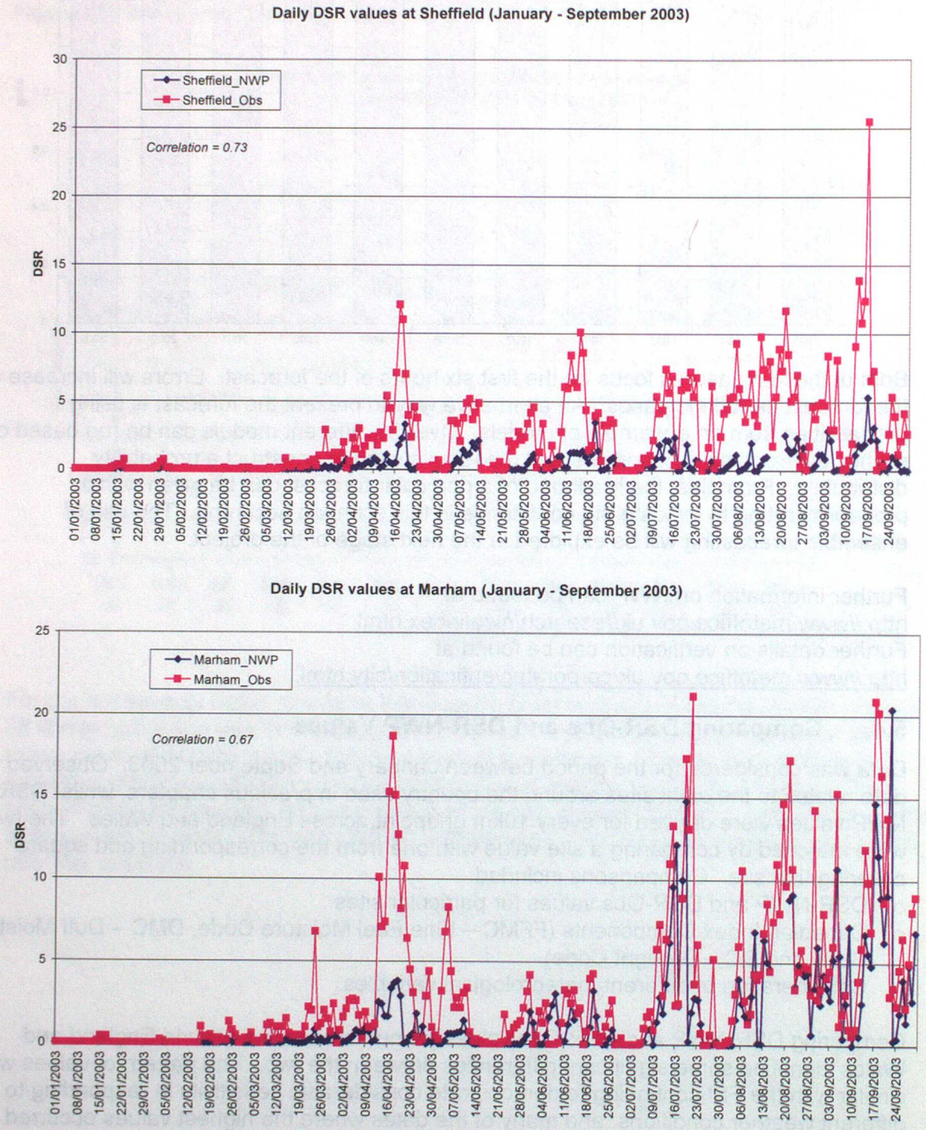
- DSR-NWP and DSR-Obs values for particular sites
- Canadian Index Components (FFMC – Fine Fuel Moisture Code, DMC – Duff Moisture Code and DC – Drought Code)
- Consideration of different meteorological variables.

Comparing DSR-NWP and DSR-Obs values for numerous sites around England and Wales identified some significant differences between the two. The pattern of values was similar with the FSI continuing to demonstrate considerable sensitivity in responding to different weather conditions, and many of the dates where the highest values occurred were common to both datasets. For example, for Spadeadam in the Cumbrian Pennines, 75% of the top 20% of days with highest DSR were common to both DSR-NWP and DSR-Obs values, confirming that the DSR-NWP is still identifying periods of high risk.

However there was a difference in the amplitude of the model output depending on the weather source of the DSR values. Those based on observed data had a greater magnitude in peak values. For example, Figure 29 illustrates the difference in values for

Sheffield and Marham, Norfolk. This shows that when the model is predicting high fire risk (e.g. mid April, late August, mid September), the difference in magnitude is in the order of fourfold, although there is some variation between the two sites. Both show a correlation of around 0.7.

Figure 29: Comparison of NWP and Observational derived DSR values for Sheffield and Marham



American research (Hoadley et al., 2004) which explored differences between observations and forecast data also found variations between predicted and actual temperature, wind speed and relative humidity values (precipitation was not considered as the study was performed during July and August in the US when there was little rainfall). They concluded that these discrepancies could have a substantial impact on predictions of fire danger if the bias was not accounted for in some way.

Comparisons were carried out for each of the weather elements to identify whether there were systematic differences with one particular element. A comparison of temperature, relative humidity, wind and rainfall for observational and NWP data for London Heathrow and Manchester Ringway (Figures 30 and 31) identified that:

- Observed temperature is consistent with that predicted by the model for Ringway. There is some evidence that model values are lower for Heathrow;
- Observed relative humidity tends to differ from the model by 5-10% particularly during the warmest months;
- Observed wind is consistently lower than the model for Ringway but for Heathrow the model tends to underestimate in the summer and overestimate in the winter;
- Rain is the most interesting. Although overall there is only perhaps 1mm difference on average between model and observational data, the model occasionally predicts significant rainfall of over 40mm which bears little relation to the observed records. This is a known, although unusual feature of the forecast model and may be due to the analysis process (described in section 5.2) which can cause a shock affecting the results in the initial forecast period.

Figure 30: Meteorological data -Observations v NWP for Ringway

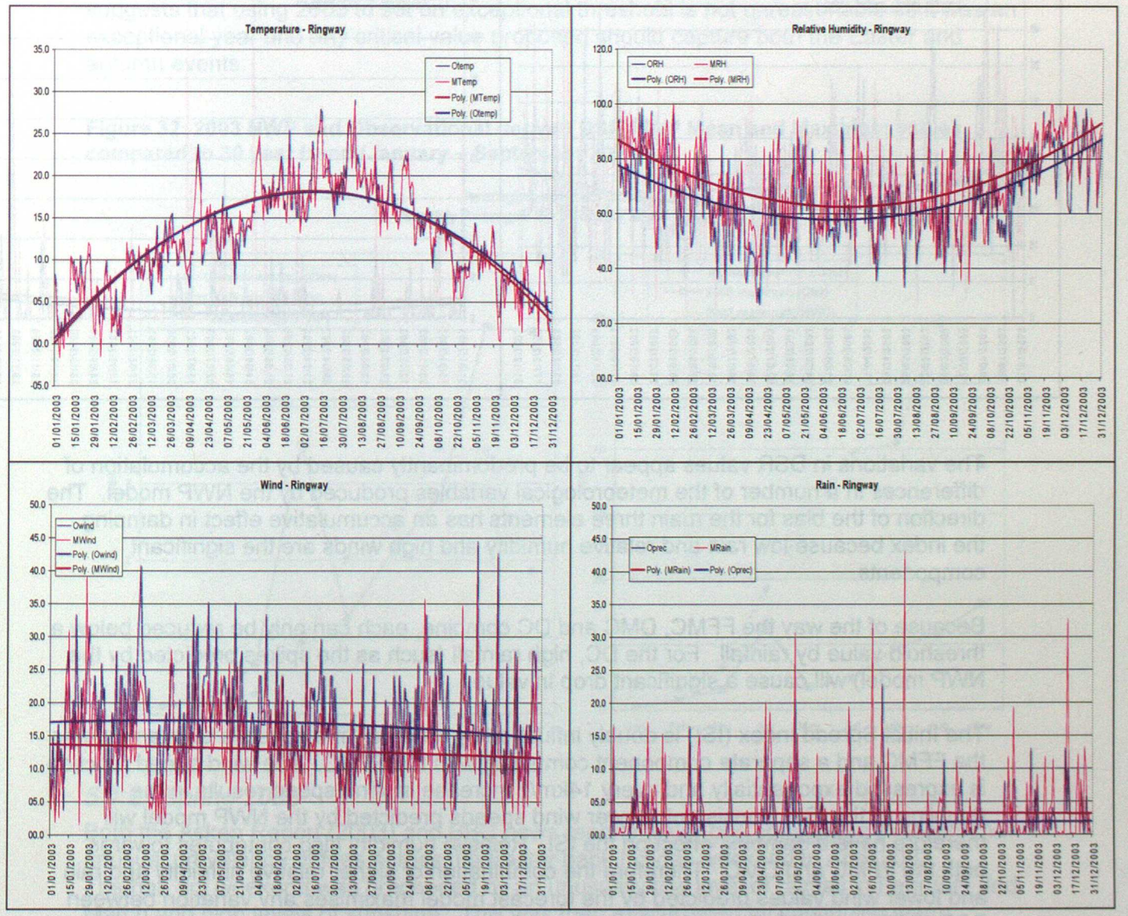
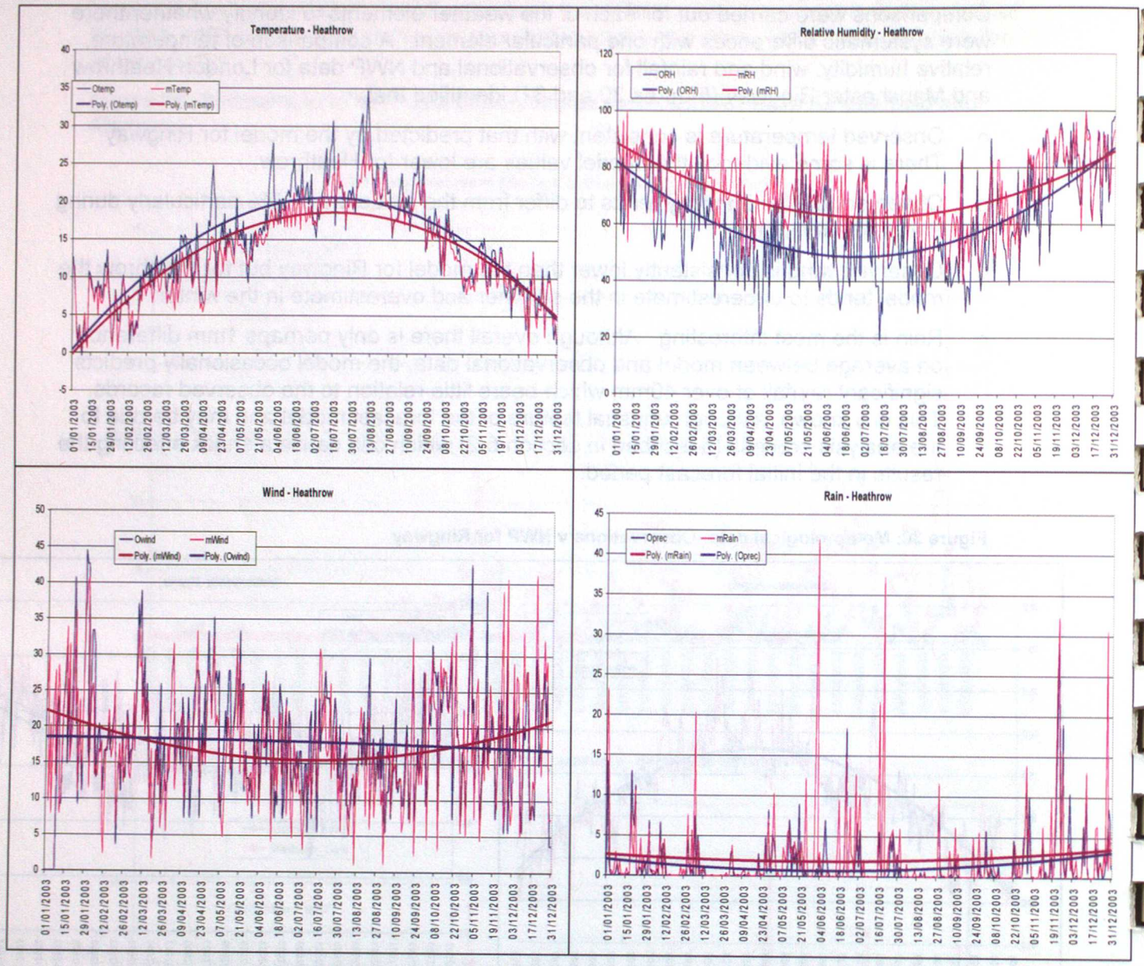


Figure 31: Meteorological data: Observations v NWP for Heathrow



The variations in DSR values appear to be predominantly caused by the accumulation of differences in a number of the meteorological variables produced by the NWP model. The direction of the bias for the main three elements has an accumulative effect in damping the index because low rain and relative humidity and high winds are the significant components.

Because of the way the FFMC, DMC and DC combine, each can only be reduced below a threshold value by rainfall. For the DC, high rainfall (such as the spikes predicted by the NWP model) will cause a significant drop in value.

The Initial Spread Index (ISI) is doubly influence by wind as wind speed is both an input to the FFMC and a separate component combining with the FFMC. The wind speed function is expressed exponentially and every 14km/h increase in wind speed results in the doubling of the ISI. Consistently lower wind speeds predicted by the NWP model will therefore have a damping effect on the ISI. Relative humidity also contributes towards both the FFMC and DMC. Therefore the combination of higher relative humidity and rain and lower wind values predicted by the forecast model maximises any variation between DSR-NWP and DSR-Obs values.

Because of the variation in timelag in the FFMC, DMC and DC in the Canadian model, the impact on the DC is most significant. The drought code has a 52 day lead time and therefore the damping effects of an overestimation in rainfall may be propagated forward over time to affect DSR values for the next 52 days.

These findings suggest that proposed threshold for defining exceptional conditions based on observational data is too high. DSR values based on NWP data are only available for 2003 at present and therefore an appropriate adjustment is derived from assessing:

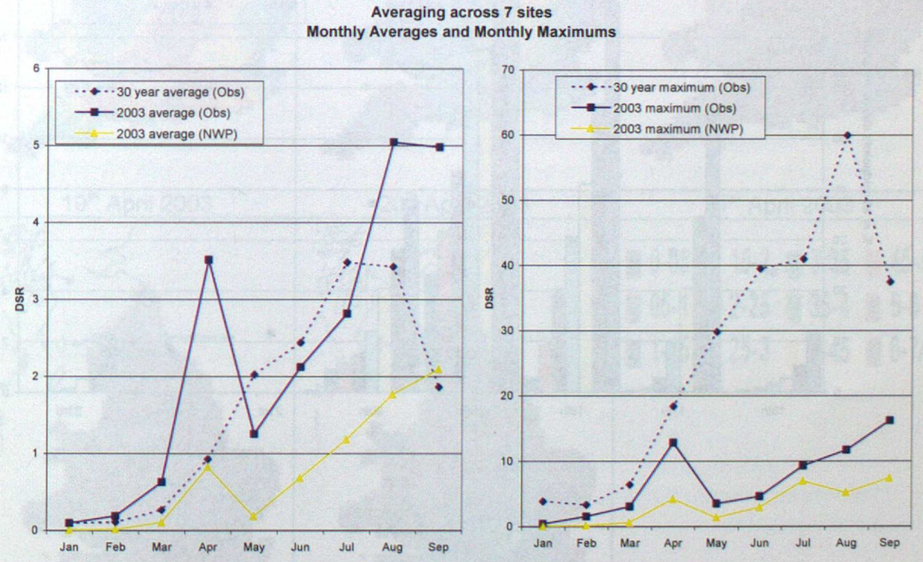
- How representative 2003 was compared to previous years;
- Whether any suggested thresholds would capture known fire events during that year.

5.4.1. 2003 In Context

DSR values based on observed and NWP data are available for 2003. In addition, DSRs from observed data is available for the 30 year period 1971 to 2003 for 7 sites geographically dispersed around the country.

Considering DSR values derived from observed data, Figure 32 shows that 2003 had far higher average values in April and September than the 30 year trend. This is consistent with the reality on the ground as significant fires occurred in both these periods. This suggests that using 2003 to set an exceptional threshold is not unreasonable as it was an exceptional year and any critical value proposed should capture both the Easter and autumn events.

Figure 32: 2003 NWP and Observational derived DSR-NWP Mean and Maximum values compared to 30 year trend (January – September 2003)



5.4.2. Spring 2003

Both the Asken Report (2003) and BBC news reports (www.bbc.co.uk/news) identify the unusual prevalence of fires across the Easter bank holiday weekend in April 2003. The hot, dry weekend was preceeded by an unusually low level of rainfall in February and March and high levels of sunshine. This was then exacerbated by continuing warm

temperatures and stiff breezes the week before Easter. Outbreaks of fire occurred across the country including Dorset, South Wales, Surrey, Teeside and the Peak District.

Whilst high levels of DSR will not indicate whether a fire is likely to start, it will capture information about the combination of ground and weather conditions likely to encourage a fire to be severe and spread rapidly. This means that fires which are difficult to access, and hence suppress, are more likely to become out of control. As in springtime drying is more pronounced on the surface layer (captured by the FFMC), fires will spread rapidly and may cover some distance. Any threshold should capture these conditions which may result in the frequency and severity of fires experienced in 2003.

Table 8: Maximum values of the DSR index calculated at 7 weather stations for April 2003

Site	Maximum	Average	90% percentile
Aberporth (Ceredigion)	4.78	0.60	2.30
Heathrow (London)	5.19	1.52	4.12
Hurn (Dorset)	6.06	1.06	2.61
Leeming (N Yorks)	3.36	0.75	2.32
Marham (Norfolk)	3.81	1.05	2.94
Ringway (Manchester)	3.24	0.46	1.36
St. Mawgan (Cornwall)	2.65	0.32	0.73

Figure 33: 16th - 23rd April 2003 - % above a range of DSR values and absolute maximum DSR value and daily maps

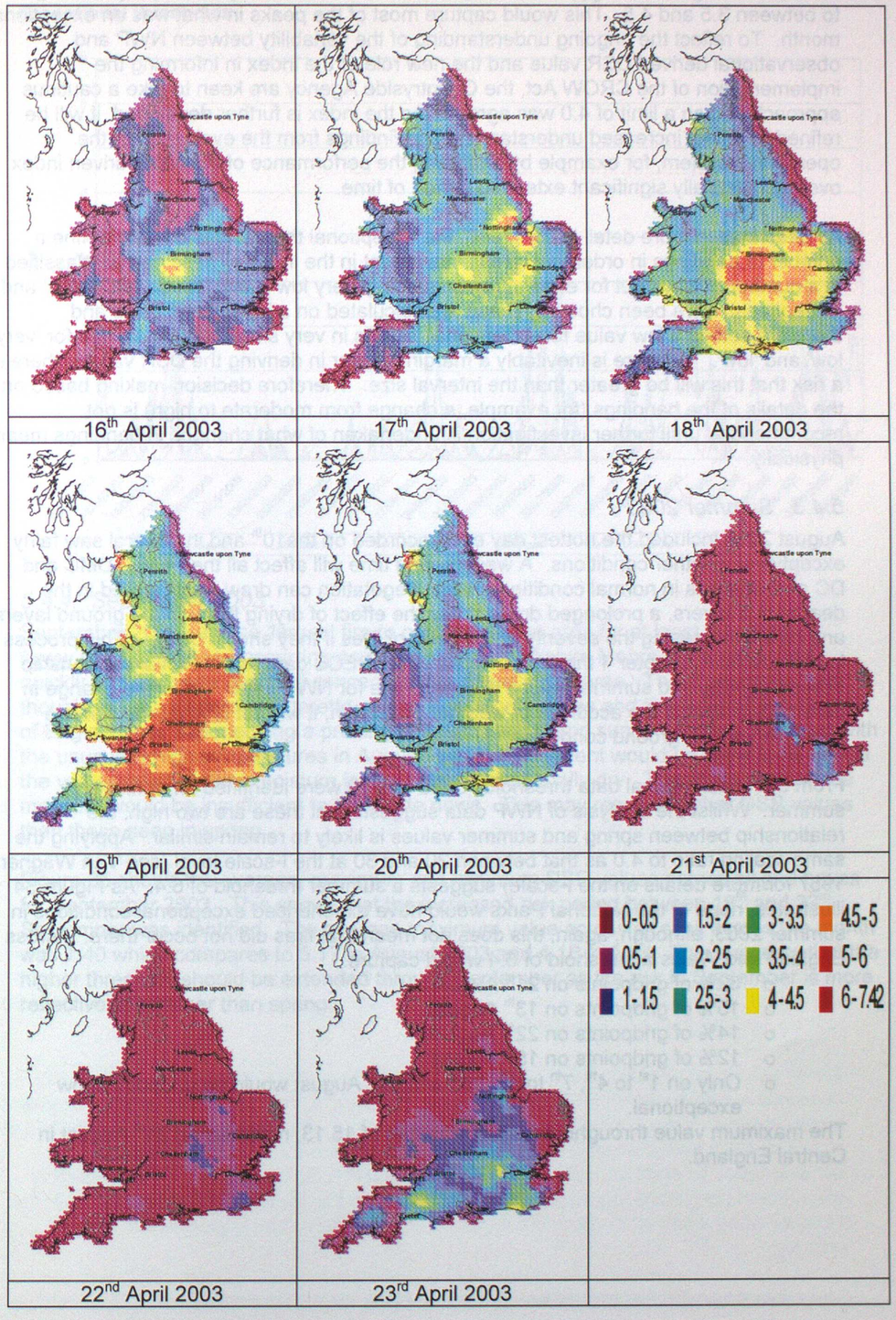


Table 8 and Figure 33 suggest that it would be reasonable to adjust the daily critical value to between 3.5 and 4.5. This would capture most of the peaks in what was an exceptional month. To reflect the ongoing understanding of the variability between NWP and observational derived DSR value and the new role of the index in informing the implementation of the CROW Act, the Countryside Agency are keen to take a cautious approach and so a limit of 4.0 was agreed. As the index is further developed, it will be refined to reflect increased understanding and findings from the evaluation of the operational system, for example by analysing the performance of the NWP-driven index over a statistically significant extended period of time.

As described in more detail in chapter 6, the exceptional threshold is used to define a number of bandings in order to express movement in the index. These can be classified in a number of ways but for ease of understanding 'very low', 'low', 'moderate', 'high' and 'exceptional' have been chosen. These are calculated on a logarithmic basis and therefore setting a low value for exceptional, results in very small banding values for 'very low' and 'low'. As there is inevitably a margin of error in deriving the DSR values, there is a risk that this will be greater than the interval size. Therefore decision-making based on the details of the bandings (for example, a change from moderate to high) is not recommended until further investigation is undertaken of what changes in bandings mean physically.

5.4.3. Summer 2003

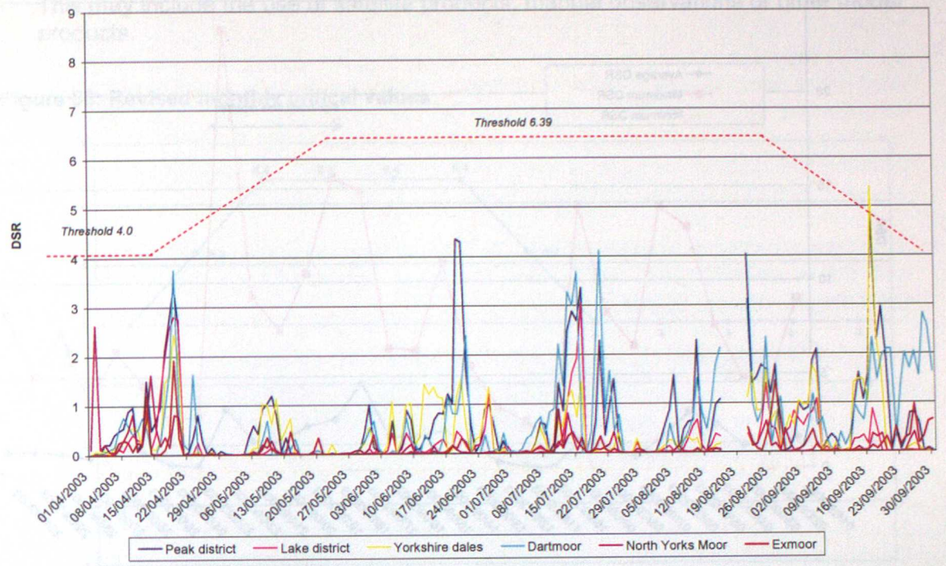
August 2003 included the hottest day ever recorded on the10th and in general saw fairly exceptional weather conditions. A warm spring time will affect all the FFMC, DMC and DC and whereas in normal conditions, some vegetation can draw water stored in the deeper duff layers, a prolonged drought has the effect of drying through the ground layers and hence increasing the severity and spread of fires if they should occur. This process is considered in chapter 4 through analysis of MORECS data and a similar relationship between spring and summer values is appropriate for NWP data. Whilst the change in data source affects the accuracy of weather prediction, it will not change the science underpinning the ground conditions.

From the observational data thresholds of 20 and 30 were identified for spring and summer. Whilst the analysis of NWP data suggests that these are two high, the relationship between spring and summer values is likely to remain similar. Applying the same scaling ratio to 4.0 as that between 20 and 30 at the I-scale level (see Van Wagner, 1987 for more details on the I-scale) suggests a summer threshold of 6.4. As Figure 34 illustrates, none of the National Parks would have experienced exceptional conditions in summer 2003, although, again, this does not mean that fires did not occur there. Across England and Wales a threshold of 6.4 would capture:

- 32% of gridpoints on 21st August
- 15% of gridpoints on 13th August
- 14% of gridpoints on 22nd August
- 12% of gridpoints on 15th August
- Only on 1st to 4th, 7th to 8th, 29th and 31st August would no gridpoint show exceptional.

The maximum value throughout August was that of 15.13, recorded on 21st August in Central England.

Figure 34: Daily DSR Values for Example Grid Squares in National Park Areas compared to Exceptional thresholds

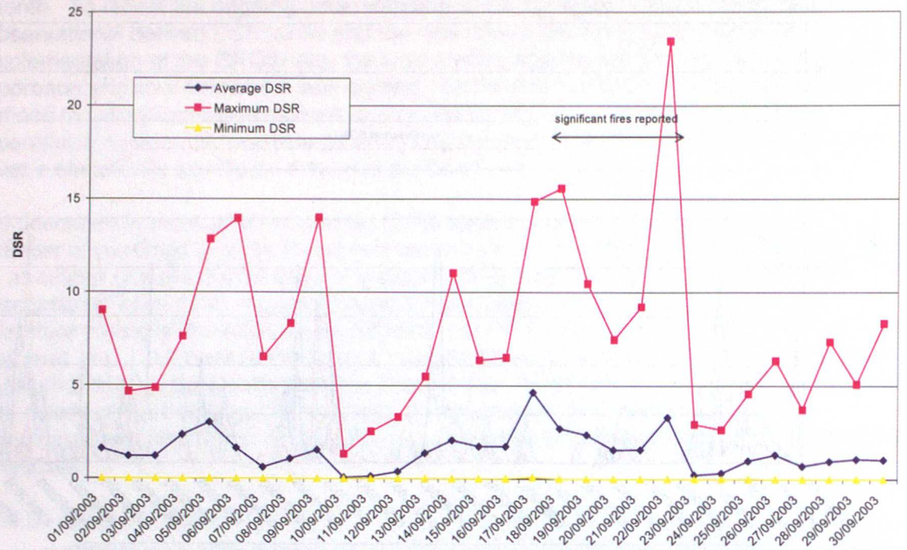


5.4.4. September 2003

September 2003 saw the 'largest fire to outbreak in the area for at least 30 years' (www.bbc.co.uk/news) occurring across the North Yorkshire Moors. This escalated quickly and caused significant concern for fire crews in the area. The likely cause was thought to be a discarded cigarette. Apart from North Wales and the North West, the rest of England was experiencing a prolonged spell of warm and sunny weather. Coupled with the unusually high temperatures in August, this autumn event would be likely to be due to the vulnerability of deep moisture layers being exceptionally dry. Therefore any surface moisture would be insufficient to penetrate down. This may result in higher DSR values than those seen in spring.

Figure 35 shows the average, maximum and minimum DSR values across all grid boxes for September 2003. This shows that the increased risk period between 18th and 23rd September was identified. The average maximum value across all sites across the month was 7.40 which compares to 5.17 in August 2003 and 4.16 in April. This suggests that the higher threshold should be extended through September as fire risk in September is more reflective of summer than spring.

Figure 35: Average, maximum and minimum DSR values across all grid boxes for September 2003



5.5. Conclusions

Testing the model using 2003 NWP data has identified a number of adjustments needed in order to implement the 5 day forecast model. There were significant differences in the magnitude of DSR values depending on whether inputs from observed or NWP data are used. These were due to differences in the forecast of the main weather elements compared to observed values and the combined influence of the meteorology in the fire severity model.

The variability of the model was very similar but peak values were much lower by up to a factor of 5 when based on NWP data. This implied that the previously suggested threshold values were too high and a more appropriate value would be about 4.0 for spring and autumn and 6.4 for summer. Consideration of September 2003 suggested that the summer threshold was more appropriate than the autumn one.

Figure 25 would therefore be revised to Figure 36 below. Again the values for May and October are for the mid month day. During May a linear variation from 4 on 30th April to 6.4 on 1st June is assumed. Also in October a linear variation from 6.4 on 30th September to 4 on 1st November is assumed.

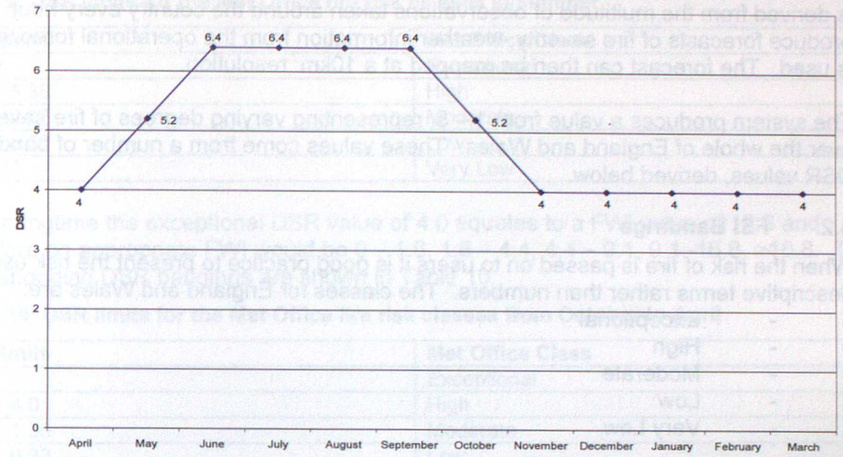
These values however do have a note of caution. As outlined above, they are mainly based on a single year of DSR-NWP values. Although spring and autumn 2003 appear to be exceptional when considered in a historical context, the extremes of the distribution of values are still based on only a few events and therefore the error margin could be considerable. In addition, with a threshold set which is quite low, the risk of predicting exceptional conditions increases and hence so does the likelihood of predicting high fire severity when weather or ground conditions in particular areas suggests this is most unlikely.

The basis on which the exceptional threshold is set may be improved by:

- Further analysis on the summer and autumn critical values including a comparison with four years of NWP derived DSR values;

- Ongoing evaluation of the performance of the model compared to actual events;
- Establishing a ground truth dataset against which model updates can be compared. This may include the use of satellite products, manual observations or other model products.

Figure 36: Revised monthly critical values



6. The Met Office Fire Severity Index

6.1. Introduction

The Met Office Fire Severity Index produces an assessment of the current day's fire severity (day 0) and the fire severity over the coming five days (days 1 to 5). It uses information such as time of year, wind speed, temperature and rainfall to produce an assessment, applying the algorithms from the Canadian DSR. The current day's weather is derived from the multitude of observations taken around the country every hour. To produce forecasts of fire severity, weather information from the operational forecast model is used. The forecast can then be mapped at a $10km^2$ resolution.

The system produces a value from 1 – 5, representing varying degrees of fire severity over the whole of England and Wales. These values come from a number of bandings of DSR values, derived below.

6.2. FSI Bandings

When the risk of fire is passed on to users it is good practice to present the risk using descriptive terms rather than numbers. The classes for England and Wales are:

5 - Exceptional
4 - High
3 - Moderate
2 - Low
1 - Very Low

Within the Canadian system there are a number of different scales which impose different restrictions on the range of values used to measure fire danger. Full details are provided in the paper by Van Wagner (1987). They vary depending on the range of values used to describe the fire risk and rate of change of values within the scales. The DSR is derived from the Fire Weather Index (FWI) value, with the DSR producing a more non-linear scale with a quicker rate of change to incorporate a measure of the control difficulty of the fire. The relationship between the DSR and the FWI is logarithmic:

$$DSR = 0.02725 f^{1.77}$$

This means that the distribution of DSR values will systematically tend towards lower values.

There are a number of ways to specify the bandings, particularly because of different regional needs (although regional variation is more of an issue for a country such as Canada where the climate may be very different from the east to west coast than for England and Wales).

Van Wagner (1987) presents a class breakdown by S.J.Murao from the Pacific Forest Research Centre which arranges the classes in a geometric progression based on an 'extreme' band beginning at 30. It should be noted however that this is a FWI value of 30 and not a DSR value: the corresponding DSR value would be 11.2.

On the Canadian operational website (http://cwfis.cfs.nrcan.gc.ca) they show FWI bandings of 0-5, 5-10, 10-20, 20-30, >30, based on observed data from about 900 stations in Canada and the northern United States. In New Zealand (http://nrfa.fire.org.nz/fire_weather/fwi/) they use a four way banding split of 0-7,8-16,17-31, and >32.

Although these may seem high compared to the critical values for England and Wales, the motivation behind the derivation of the scale is different. The Fire Severity Index has

been developed specifically in response to the CROW Act to aid in decisions about land closure due to exceptional fire risk.

The report suggested that for England and Wales a suitable DSR lower limit for the exceptional class for summer is 6.39. This equates to a FWI value of 21.8 and therefore a sensible FWI scale would be 0 - 1.9, 1.9 – 5.3, 5.3 – 11.4, 11.4 – 21.8, >21.8, giving DSR bandings as listed in Table 9.

Table 9: DSR limits for the Met Office fire risk classes in summer

DSR limits	Met Office Class
> 6.39	Exceptional
2.03 – 6.38	High
0.53 – 2.02	Moderate
0.08 – 0.52	Low
0 – 0.07	Very Low

For Springtime the exceptional DSR value of 4.0 equates to a FWI value of 16.8 and therefore an appropriate FWI would be 0 – 1.6, 1.6 – 4.4, 4.4 – 9.1, 9.1 -16.8, >16.8. The corresponding DSR bandings are shown in Table 10.

Table 10: DSR limits for the Met Office fire risk classes from October to April

DSR limits	Met Office Class
> 4.0	Exceptional
1.36 – 4.0	High
0.34 – 1.35	Moderate
0.06 – 0.33	Low
0 – 0.05	Very Low

In May and October a linear variation between the class limits in Tables 9 and 10 is used.

6.3. Factors to consider when defining exceptional conditions

In defining exceptional conditions, any guidance to add decision making should consider the FSI on day 0 and day 1 as the forecast is less accurate as time goes forward. In general, any guidance produced to define what constitutes exceptional conditions should reflect the following:

For the start of an exceptional period

- The Met Office daily FSI for day 0 or day 1 (the current or following day) should be at exceptional.

For the end of an exceptional period

- The Met Office daily FSI for day 0 must be Very Low, Low, Moderate, or High for 5 consecutive days.

Or

- The Met Office daily FSI for day 0 must be Very Low or Low for 3 consecutive days.

The first criteria for the end of an exceptional period refers mainly to the summer situation when rainfall is light so that the ground and vegetation remain dry after a severe fire risk spell, but the temperature and windspeed have dropped. The second circumstance could refer to a spell of high fire risk ending with heavy rain, or in spring when warm breezy weather is replaced by damper conditions with more normal temperatures. Both depend on the fact that no exceptional conditions are forecast.

The Met Office FSI is available as averages over a grid of 10 km x 10 km squares covering England and Wales. These show the Met Office FSI for the current day. There are also forecasts of the Met Office FSI available on the grid from 1 to 5 days ahead. These can be used for planning and management purposes for example when considering whether to lift a restriction or pending a decision about imposing a restriction.

7. Summary of Findings

The Countryside Agency, Countryside Council for Wales and the Forestry Commission have responsibilities for managing public access introduced under the Countryside and Rights of Way Act 2000 (abbreviated to CROW). These bodies have to decide whether public access to areas of access land should be restricted when there is an exceptional fire risk. While CROW will allow public access on foot to areas of land in England and Wales it also gives the relevant authorities power to restrict public access where they are satisfied that by reason of exceptional conditions of weather or any exceptional change in the condition of the land, the exclusion or restriction is necessary for the purposes of fire prevention.

The fire risk of an area of land is determined by a combination of the natural fuel present and the weather conditions. However, it is the weather which determines the day to day change in fire risk. The Met Office and ADAS have developed a Fire Severity Index (FSI) that gives an objective way to show when exceptional conditions occur. This report gives details of the choice of a fire severity index for England and Wales.

1) Several fire severity indices were evaluated initially. The performance of the best three were compared for:

- the hot, dry summers with high fire risk in 1976 and 1995
- the warm, windy spells with high fire risk in spring of 1980 and 2003
- the highest 25 values at Heathrow
- Statistical properties.

2) Of the three indices tested, the Canadian Daily Severity Rating (DSR) index emerged as the best indicator of fire risk for England and Wales. Its strengths are that:

- it emphasises high risk periods and increases noticeably/dramatically;
- it can identify risk caused by prolonged drought;
- it can identify risk due to combinations of high winds/low humidity/warm temperatures when drought is absent or not severe. This is particularly important for fire risk in spring in England and Wales;
- all of the weather inputs required are available from forecast data;
- it is based on physical process modelling with a documented scientific basis;
- it is in use in several countries as a fire risk indicator where it is well regarded for its practicality and scientific development.

3) The water balance model MORECS, often used in fire risk assessment in the UK, performed poorly as a fire risk estimator compared with the DSR index.

4) From a consideration of 30 years of historical weather data and 2003 NWP data the lower limits of the DSR for the exceptional fire risk are recommended as 6.4 from June to September and 4.0 from November to April. A linear change during May and October is proposed.

5) A Met Office Fire Severity Index was defined in terms of ranges of the DSR on a 5 point descriptive scale: Very Low, Low, Moderate, High, and Exceptional which apply throughout the year. These fire risk classes are presented daily as averages for National Grid 10km x 10km squares for England and Wales.

6) Guidance defining the start and end of an Exceptional fire risk period should reflect the following:

For the start of an exceptional period

- The Met Office daily FSI for day 0 or day 1 (the current or following day) should be at Exceptional.

For the end of an exceptional period

- The Met Office daily FSI for day 0 must be Very Low, Low, Moderate, or High for 5 days.

Or

- The Met Office daily FSI for day 0 must be Very Low or Low for 3 days.

7) The Met Office FSI indicates when weather or ground conditions combine to give an increased risk of fires spreading readily if they do occur. However additional local site factors such as the vegetation type need to be assessed for precise fire management or vegetation management. Local site factors are taken into account in the determination of the necessity for a restriction on public access by the relevant authority.

8) The Met Office FSI will be continually reviewed and developed. This may include:

- Further analysis on the summer and autumn critical values including a comparison with four years of NWP derived DSR values;
- Ongoing evaluation of the performance of the model compared to actual events;
- Improved resolution of data sources such as incorporating radar data;
- Establishing a ground truth dataset against which model updates can be compared. This may include the use of satellite products, manual observations or other model products.

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APPENDIX A: List of Observers for 2003 Trial

Site Num.	Contact	Organisation	Grid Reference
1	Gordon Danks	Peak District NPA	SK204997
2	Dave Farmery	FC	SH 754 054
3	Bob Clark	FC	SN 834038.
4	Martin Webb	FC	SS414014
5	Marie Makins	FC	TL 815878
6	James Lamb	Yorkshire Dales NPA	SD965941
7	Neville Geddes	FC	SD335943
8	Neville Geddes	FC	NY631935
9	Neville Geddes	FC	NU067021
10	Sue Bellis	FC	SU805425
11	John Lewis	FC	SN875797
12	Richard Ball / Gary Mitchell	Brecon Beacons NPA	SN978265
13	Bernie McLinden	North Yorks Moors NPA	NZ 736093
14	Bernard	ADAS	SN802770
15	Nick Wythe	FC	SO 188683
16	Clive Thomas	FC	SN684865
17	Alan Hubbuck	FC	SN 817035
18	Alan Pritchard	Snowdonia NPA	SH647604
19	Dion Jones	Snowdonia NPA	SH553504
20	John Stafford	FC	TQ 727 337
21	Chris Botting	FC	SN455617
22	Richard Vaughan	Pembrokeshire Coast NPA	SN063374
23	R. Ford	Capel Isaac, Wales	SN593269
24	Jane Wilson	Northumberland NPA	NY935813
25	Joseph Jones	Snowdonia NPA	SH717660
26	Myfyr Tomos	Snowdonia NPA	SH728120
27	Tony Bushby	Lake District NPA	SD3684
28	John Wilcockson	Bourne, Lincolnshire	TF077214
29	Ian Hurst	Peak District NPA	SK079871/SK051844
30	Robert Mayo	FC	S0515054
31	Eleanor Brown	Countryside Agency	S0779449
32	Jez Martin	Poole Borough Council	SZ031952

FC = Forestry Commission
NPA = National Park Authority

APPENDIX B: Table of 25 Highest Values at Heathrow

DSR		FDI		HRI	
Date	Value	Date	Value	Date	Value
17-Jul-72	34.1	08-Aug-75	12.98202	03-Aug-75	96
31-Aug-72	33.3	26-Jun-76	12.74315	04-Aug-75	100
08-Aug-75	32.9	*30-Jun-76*	24.0786	08-Aug-75	100
29-Jun-76	33.2	*01-Jul-76*	12.35144	28-Jun-76	100
30-Jun-76	70.2	*02-Jul-76*	14.76814	29-Jun-76	96
01-Jul-76	69.6	*03-Jul-76*	14.25646	*30-Jun-76*	96
02-Jul-76	48	*05-Jul-76*	13.03518	*01-Jul-76*	96
03-Jul-76	42.7	*06-Jul-76*	12.09313	*02-Jul-76*	100
05-Jul-76	34.1	07-Jul-76	12.13959	*03-Jul-76*	100
06-Jul-76	38.6	08-Jul-76	11.83589	*05-Jul-76*	96
21-Aug-76	44.8	21-Aug-76	12.3212	*06-Jul-76*	96
22-Aug-76	61.5	22-Aug-76	15.42306	07-Jul-76	96
23-Aug-76	47.9	23-Aug-76	13.36039	12-Jul-76	96
26-Aug-76	48.2	24-Aug-76	13.3198	05-Jul-83	96
16-May-80	33.3	25-Aug-76	15.30524	19-Aug-83	96
19-Aug-83	38.6	26-Aug-76	16.45906	20-Aug-87	96
22-Jul-90	34.3	08-Sep-76	11.78726	15-Jul-90	96
02-Aug-95	53	03-Aug-90	12.76058	21-Jul-90	96
03-Aug-95	53.8	29-Jul-95	11.21411	02-Aug-90	100
10-Aug-95	39.2	01-Aug-95	13.23436	03-Aug-94	96
05-Aug-96	35.2	*02-Aug-95*	14.6553	28-Jun-95	96
31-May-97	35.3	*03-Aug-95*	13.96811	10-Jul-95	96
01-Jun-97	54.9	31-May-97	12.16663	25-Jul-95	96
02-Jun-97	63.1	01-Jun-97	12.2177	*01-Aug-95*	100
05-Jun-97	52	05-Jun-97	11.66311	*02-Aug-95*	100

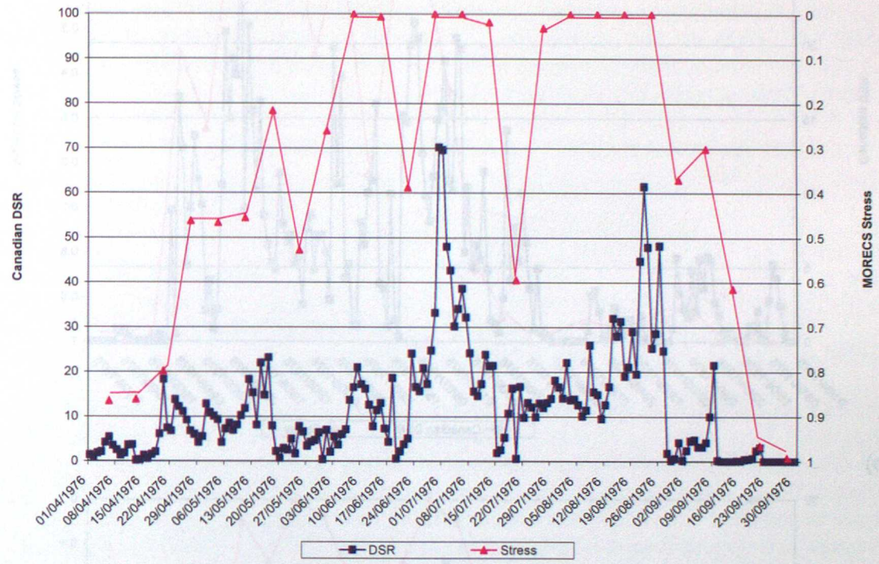
Shaded values refer to common dates across all three indices.

APPENDIX C: Comparison of Canadian DSR to MORECS

As an example of MORECS stress values they are compared with the daily Canadian DSR in 1976 and 1995 in Figures C1 and C2 for Heathrow and Leeming.

Figure C1: The Canadian DSR (daily) at Heathrow and MORECS stress (rough grazing, median soil) for MORECS square 161 (west London) in (a) 1976 and (b) 1995. Note that the stress is plotted reversed so that both indices rise and fall in the same manner.

(a)



(b)

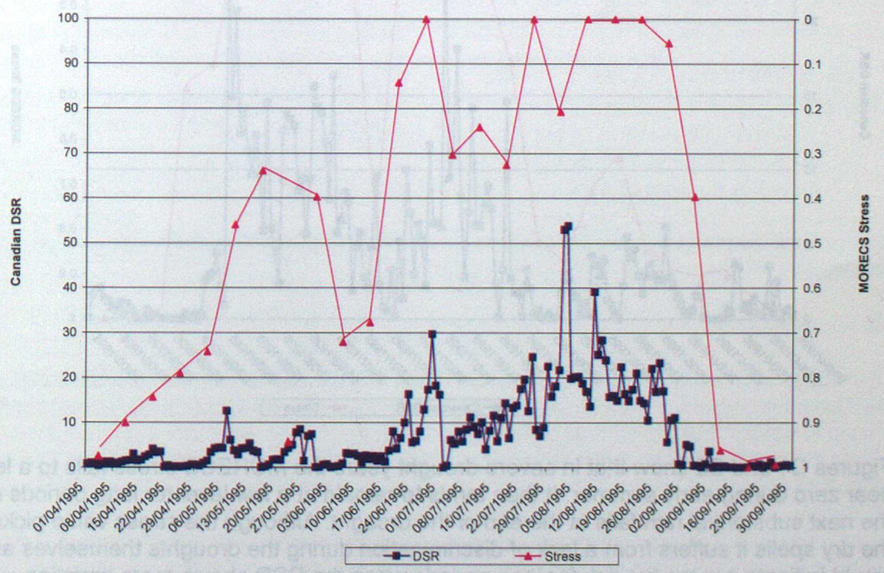
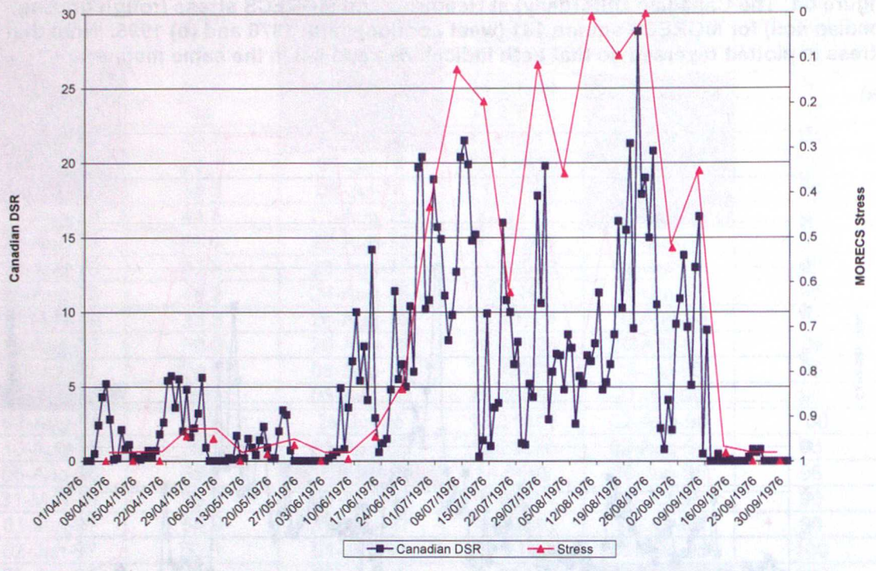
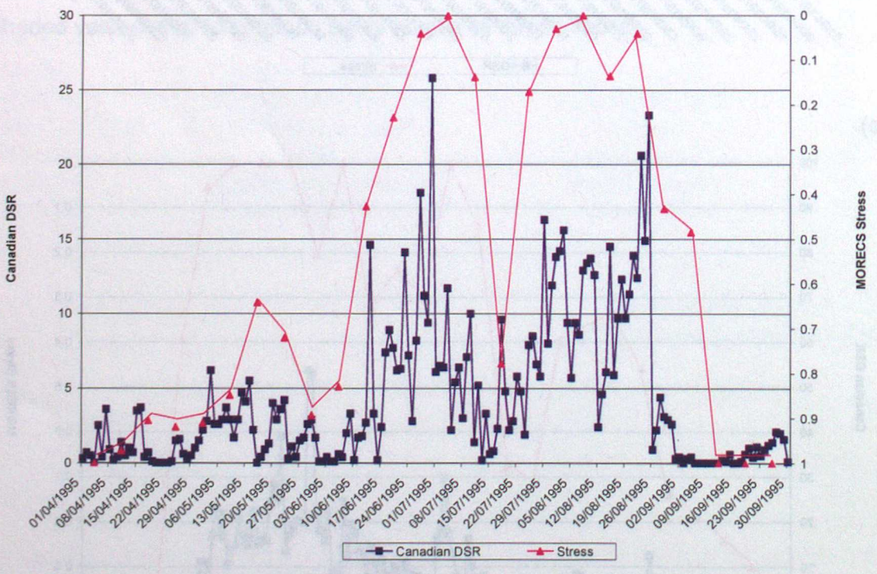


Figure C2: The Canadian DSR (daily) at Leeming and MORECS stress (rough grazing, median soil) for MORECS square 93 (part of North Yorkshire) in (a) 1976 and (b) 1995. Note that the stress is plotted reversed so that both indices rise and fall in the same manner.

(a)



(b)



Figures C1 and C2 show that in severe drought years the MORECS stress falls to a level near zero during early summer. It then tends to remain at a low level for long periods until the next substantial rain falls at the end of the drought. Although the stress value picks out the dry spells it suffers from a lack of discrimination during the droughts themselves as it would indicate severe fire risk for long periods when the DSR shows more variation.

Similar analysis for spring in 1980 shows that although the MORECS stress shows the high fire risk period in mid May, it entirely misses a peak in the first week of May. This is because the soil moisture levels were still high in early May so that the actual evaporation was close to the potential rate. The stress index was close to 0.9. By mid May the soil had dried out somewhat and the stress had fallen to nearer 0.5.

In summary the MORECS stress assesses drought, not fire risk. MORECS cannot indicate high fire risk when the soil is moist. This is the normal situation in spring when the surface might be dry, but the deeper soil layers are moist.

APPENDIX D: Statistical Analysis

The following report has been provided by ADAS. It investigates the relations between the observations of fire risk in 2003 and the concurrent values of several fire indices.

Statistical Techniques

The selection of the model to use was done using non-parametric statistical tests. The test used in particular was the Kruskall Wallis test. This is a test that looks at the differences between groups of observations and has a null hypothesis that there is a random distribution of ranks across the groups. If the null hypothesis is false, we expect a systematic distribution across the groups. In simple terms, if the null hypothesis is true we expect the mean rank of each group to be the same, but if the null hypothesis is false, we expect the mean ranks to be different.

The Kruskall Wallis test statistic, H, is calculated as follows:

$$H = \left[\frac{12}{N(N+1)} \sum n\bar{R}^2 \right] - 3(N+1)$$

Where:

N is the total number of scores
R is the mean rank for each level of the variable
n is the number of scores in each of the variables

This test was applied to each fire risk model for every observer with the observation groups Nil, Low, Medium, High and Exceptional risk being the levels of the test. Further to this a secondary test was applied to test whether any differences observed in the mean ranks of the model were significant by calculating the critical differences between each group of observations. This is known as Post Hoc comparison and if the difference between two ranked means is greater than the Critical Difference then it is significant, if it is less than the critical difference, it is not significant.

The Critical Difference is calculated as follows:

$$\text{Critical Difference}_{0.05} = 2.394 \sqrt{\frac{N(N+1)}{12}\left(\frac{1}{n_1} + \frac{1}{n_2}\right)}$$

Where:

N is the total number of subjects in the experiment
n_1 is the number of subjects in group 1
n_2 is the number of subjects in group 2

Using significance tables for the H value and including the Critical Difference values the statistically strong models could be identified.

Model Selection

Looking at each observer on an individual basis it was clear to see that models such as the Canadian model, the Peak District models and the Dorset Heath models were giving strong H values, but the Critical Differences between groups were not being achieved. On closer inspection the reason for the Critical Differences not being achieved was due to the lack of observations in the higher risk levels, and as such a robust statistical test could not be carried out. As a result, it was decided to run the tests on all observers at all locations as one set. This not only would provide a larger, more robust dataset, but would also allow for a worst-case scenario assessment of the models by accounting for the variability of observers opinions.

Running the test for all observers gave a much more reliable and significant result. Table D1 shows the counts of observations in each risk class for all observers. As can be seen from this table there is a good distribution of observations, with low counts in the classes we might expect, Nil and Exceptional.

Table D1: Counts of the number of observations for each risk class for all observers

	Nil	Low	Medium	High	Exceptional
Observations	404	634	284	158	56

Table D2 shows the models had significant critical differences between each class for all classes. The values in the table are the mean rank for each class. As would be expected, the mean rank increases with each class, the low risk categories being the low ranking observations through to the high risk rankings being the highest ranking observations. The greater the separation between these classes, the better the model is perceived to be and the bigger the H and Critical Difference values.

Table D2: The mean rank for each of the classes for all models that had significant Critical Differences between all classes

MODEL	Nil	Low	Medium	High	Exceptional
Canadian Forest Fire Danger Rating System Danger Severity Rating	585.60	705.29	905.65	1060.35	1284.63
Peak District Fire Danger Rating for Grass	562.74	710.05	935.29	1047.98	1280.23
Peak District Fire Danger Rating for Rough Grazing	568.75	711.09	930.80	1043.83	1259.55
Dorset Heath Fire Danger Rating for Grass	660.33	732.86	815.42	950.31	1201.46
Dorset Heath Fire Danger Rating for Rough Grazing	651.97	733.04	819.96	964.45	1196.82
Dorset Heath Fire Danger Rating for Conifer Trees	648.49	730.12	838.56	956.32	1183.57
Dorset Heath Fire Danger Rating for Deciduous Trees	656.33	733.96	820.69	951.27	1188.34

Table D3 shows the H values calculated for each of the models. The magnitude of the H value is an indicator of the degree of differences between groups.

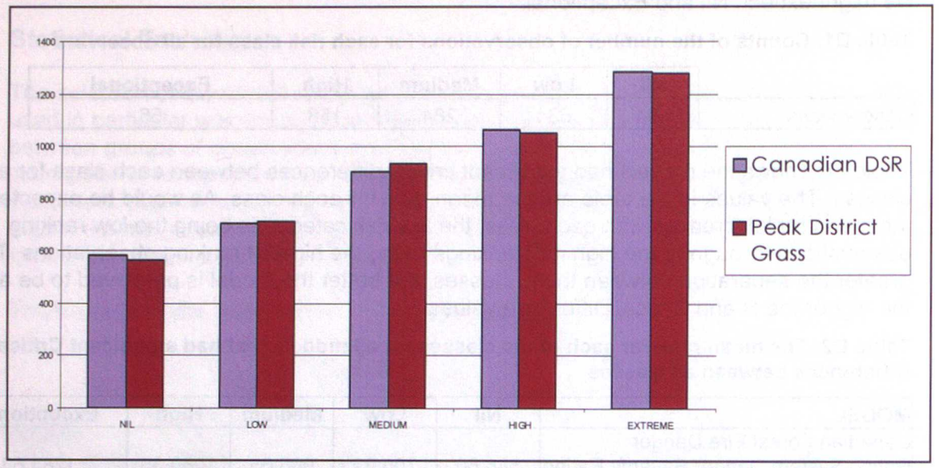
Table D3: The H values calculated for all observations for all models that had significant Critical Differences between all classes

MODEL	H Value
Canadian Forest Fire Danger Rating System Danger Severity Rating	255.95
Peak District Fire Danger Rating for Grass	278.38
Peak District Fire Danger Rating for Rough Grazing	263.10
Dorset Heath Fire Danger Rating for Grass	114.20
Dorset Heath Fire Danger Rating for Rough Grazing	121.82
Dorset Heath Fire Danger Rating for Conifer Trees	121.78
Dorset Heath Fire Danger Rating for Deciduous Trees	113.61

Using the information presented it is possible to begin to select the appropriate model to use. From Table D2 and D3 it is clear to see that the level of separation seen between classes for the Dorset Heath models is not as significant as that seen in the other models. This allows us to discount the Dorset Heath models as viable options. From this, the Peak District models and the Canadian Model are the remaining options. Figure D1 shows a graphical representation of the mean ranks for each class for the Canadian Forest Fire

Danger Rating System Danger Severity Rating and the Peak District Fire Danger Rating for Grass.

Figure D1: Mean ranks for each class for the Canadian Forest Fire Danger Rating System Danger Severity Rating and Peak District Fire Danger Rating for Grass



The use of Figure D1 allows for easier visualisation of the differences between the risk classes for each model. As can be seen from the graph, the patterns and differences observed are almost exactly the same. Figure D2 and Figure D3 show the two indices for the same time period (01/05/02 to 30/09/03).

As can be seen from the graphs, the Canadian model produces a much more continuous scale, distinguishing well between exceptional and high values. The Peak District model, however, has a more stepped scale and does not show up as well the subtle differences in the fire risk. This can be seen clearly with the peak in fire risk at Easter in 2003. The Canadian model (Figure D2 records its maximum value at this point, while in the summer of the same year the peak is lower than that seen at Easter. The Peak District model (Figure D3) fails to pick up on this difference, predicting the same risk at Easter as it does in the summer. So while both models appear to show very similar predictions for fire risk, the Canadian model seems to offer a more sensitive prediction.

As the fundamental idea of using a model is to identify exceptional cases and allow for long-term return period analysis it is felt that the Canadian model (DSR) provides a better proposition. The stepped nature of the Peak District model does not allow for the identification of such exceptional cases.

Figure D2: Five-Day average of the Canadian Forest Fire Danger Rating System Danger Severity Rating for Cottesmore

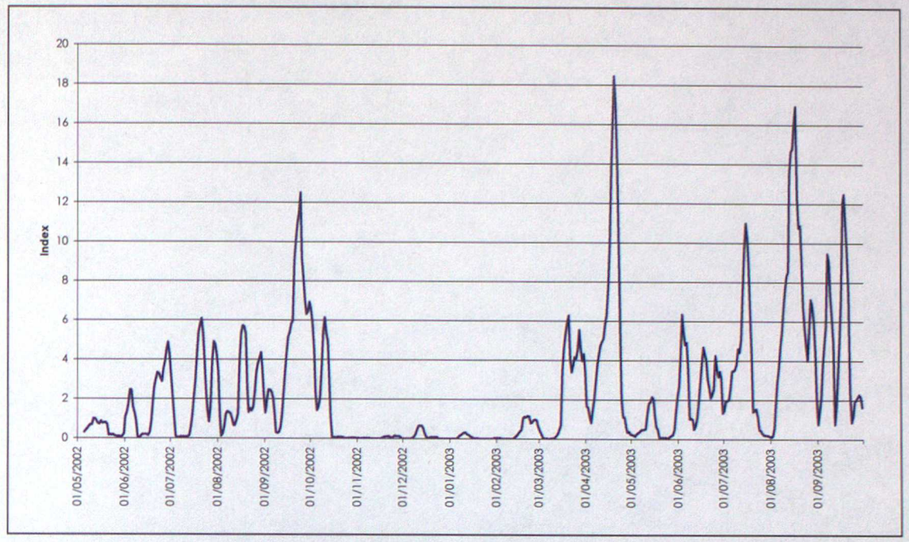
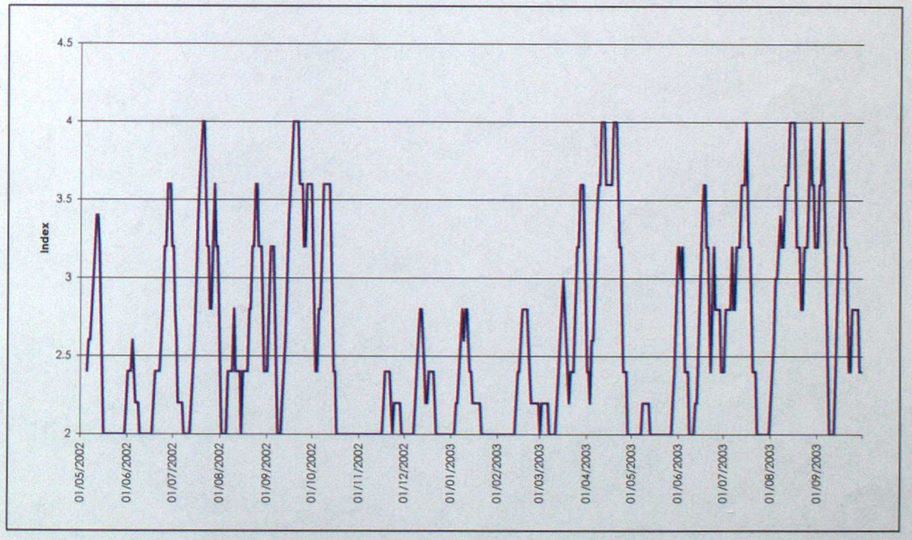



Figure D3: Five-day average of the Peak District Fire Danger Rating for Grass for Cottesmore